EXPRESS MAIL NO. EV529789889US

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : F15D 1/02, B01D 17/02, 45/16	A1	(11) International Publication Number: WO 90/15256 (43) International Publication Date: 13 December 1990 (13.12.90)

(21) International Application Number: PCT/BE90/00027

(22) International Filing Date: 7 June 1990 (07.06.90)

(30) Priority data:

362,491	7 June 1989 (07.06.89)	US
362,492	7 June 1989 (07.06.89)	US
517,625	30 April 1990 (30.04.90)	US

(71) Applicant *(for all designated States except US)*: AEROSEP SOCIETE ANONYME [LU/LU]; 11, rue Aldringen, L-2960 Luxembourg (LU).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)* : MALDAGUE, Pierre [BE/BE]; 232, avenue Winston-Churchill, Boite 11, B-1180 Brussels (BE).

(74) Agents: VAN MALDEREN, Michel et al.; Office Van Malderen, 22/43, avenue J.S.-Bach, B-1080 Brussels (BE).

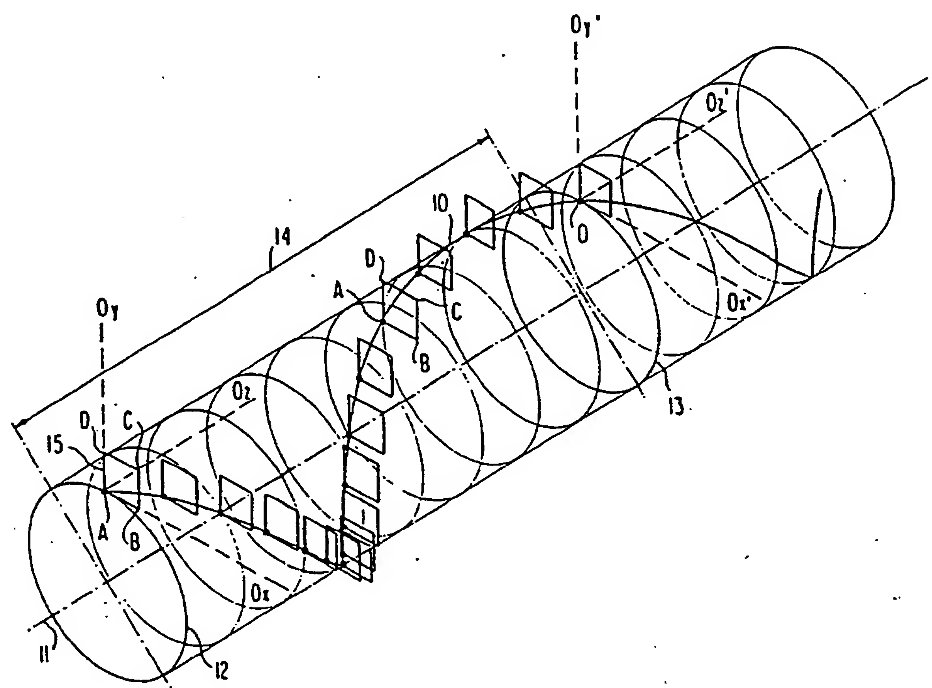
(81) Designated States: AT, AT (European patent), AU, BB, BE (European patent), BF (OAPI patent), BG, BJ (OAPI patent), BR, CA, CF (OAPI patent), CG (OAPI patent), CH, CH (European patent), CM (OAPI patent), DE*, DE (Utility model)*, DE (European patent)*, DK, DK (European patent), ES, ES (European patent), FI, FR (European patent), GA (OAPI patent), GB, GB (European patent), HU, IT (European patent), JP, KP, KR, LK, LU, LU (European patent), MC, MG, ML (OAPI patent), MR (OAPI patent), MW, NL, NL (European patent), NO, RO, SD, SE, SE (European patent), SN (OAPI patent), SU, TD (OAPI patent), TG (OAPI patent), US.

Published

With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: CURVED FLUID TRANSLATION SYSTEMS

(57) Abstract



Several forms of non-rotating translation apparatus and processes are disclosed, which may for example be used for aerodynamic or hydrodynamic separation of micron and submicron size dispersed particles from fluid flowing along elongated, congruent flow paths in confined streams. A rotating centrifugal acceleration field is generated which may be utilized in the flowing fluid to cause separation. A preferred embodiment is a cluster of plural rows and columns of plural, laterally and vertically contiguous congruent helical ducts with increasing and decreasing aspect ratio that undulate along the length thereof in each of two directions transverse to the flow paths. The separator may be used at transonic velocities of gaseous streams with an upstream flow expanding nozzle supplying micron size condensed aerosols and a downstream recompressing nozzle, thus pumping in the gas the condensation heat of the extracted vapor. It may also be used for breaking down up to micron size atomized liquids with larger size, for causing physical or chemical reactions between liquid aerosols and their carrier gas and for extracting said aerosols after the reaction.

DESIGNATIONS OF "DE"

Until further notice, any designation of "DE" in any international application whose international filing date is prior to October 3, 1990, shall have effect in the territory of the Federal Republic of Germany with the exception of the territory of the former German Democratic Republic.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	ES	Spain	MC	Monaco
AU	Australia	FI	Finland	MG	Madagascar
BB	Barbados	FR	France	ML	Mali
BE	Belgium	GA	Gabon	MR	Mauritania
BF	Burkina Fasso	GB	United Kingdom	MW	Malawi
BG	Bulgaria	GR	Greece	NL	Netherlands
BJ	Benin	HU	Hungary	NO	Norway
BR	Brazil	IT	Italy	RO	Romania
CA	Canada	JP	Japan	SD	Sudan
CF	Central African Republic	KP	Democratic People's Republic of Korea	SE	Sweden
CG	Congo			SN	Senegal
CH	Switzerland	KR	Republic of Korea	SU	Soviet Union
CM	Cameroon	LI	Liechtenstein	TD	Chad
DE	Germany, Federal Republic of	LK	Sri Lanka	TG	Togo
DK	Denmark	LU	Luxembourg	US	United States of America

CURVED FLUID TRANSLATION SYSTEMS

Field of the Invention

The invention relates to fluid translation systems, systems for moving fluids, with or without dispersed particles, through confined flow paths having curved centerlines. More particularly, the invention relates to equipment and processes for translating fluids for conveying, particle-generating, flow-shaping, atomizing, chemical or physical reaction, separation, heat-exchange and any other purpose.

Background Art

There are many systems for translating gaseous streams. A characteristic commonly sought in these systems is generation of secondary flows by deflecting the stream, thus inducing strong centrifugal acceleration fields.

For example, there have been experiments with gas-solids separators having helically coiled ducts that produce secondary flows. These ducts have been described as having flowpaths generated by rotating a circle and a plane which contains it about an axis that is also in the plane, while the center of the circle is retained on a regular helix having the same axis.

Proponents of helical coil particle separators claim they are highly efficient for separating small particles and involve relatively low flow resistance, capital investment and maintenance costs. However, because these devices occupy a large specific volume per unit of flow rate, they are usually

employed only in low flow rate systems. Also, it has been found that these separators have limited ability to recover submicron particles from aerosols composed mostly of submicron particles.

There is therefore a need for highly efficient separation systems, including devices and processes, that entail relatively low flow resistance, capital investment and maintenance costs, which readily handle streams with high flow rates, which efficiently separate submicron aerosols and which are otherwise suitable for industrial uses. Considering the characteristics and performance of the helical duct separators of years past, one would not normally expect them to fulfill this need.

Abundant literature shows that after earlier experiments with helical coil separators, much effort has been expended on attempting to fully understand the types of flow which occur in many different forms of curved pipes, including secondary flows. Among the main categories of flow discussed in published theoretical and experimental studies are steady conditions of flow in the inlet regions of curved pipes; fully developed flow in curved pipes; flow in spiral tube coils and pipes with periodically- or non- varying curvature; velocity distribution in bends; loss coefficients for bends; and bend interactions. Besides these there are many other categories, some of which relate to flow in rotating curved pipes and unsteady (oscillatory or pulsating) flow in curved pipes.

While much of the literature emphasizes theoretical or experimental investigations rather than practical applications, various applications are disclosed, including particle separation, heat exchange, bio-mechanical engineering, continuous chemical reactors, hydraulic or pneumatic conveyance of solids in pipes and others. Flows

in ducts having cross-sections of many different shapes have been analyzed, such as square, rectangular, circular, semi-circular and triangular.

Among the findings of these investigations are that secondary flow appears in the inlet regions of pipes, increases steeply, attains its maximum intensity in the early stages of flow development, and then weakens asymtotically further downstream. In laminar flow through helically coiled pipes of circular and annular cross-section the fully developed secondary flow generally takes the shape of one pair of counter-rotating vortices. However, it has also been reported that when the pitch of a helical coil is large, the symmetry of the secondary flow streamlines is destroyed, because a unidirectional swirl due to torsion is superimposed on the symmetrical two-vortex flow. When the curvature of a pipe is significant, the primary velocity distribution of the flow is entirely altered by the secondary flow, and a considerable increase in resistance is observed. In Archimedean spiral coils, the flow does not develop fully, since the radius of curvature varies continuously in the downstream direction. In periodically curved pipes of varying curvature, in which the primary velocities of the flow are higher toward the side having a larger local curvature, the flow streamlines shift from side to side, seeking a less tortuous path than those described by the walls.

Experiments made in 90° bends with a radius ratio of about 2.3 between the radius of the bend and the hydraulic radius of its cross-section have shown that the peak secondary velocities occur at about 60° from the inlet, and are about 0.6 times the average primary velocity in laminar flow against about 0.4 times said average velocity in turbulent flow. According to experiments carried out with two commercial screw elbows closely spaced after one another in

combination at angles of about 90°, a strong swirl is created in the downstream portion and the swirl velocity amounts at its maximum to 0.9 times the average primary velocity of the flow. The swirl can persist for 160 pipe diameters in the downstream direction.

Notwithstanding the vast array of information available on the subject of flow in ducts with and without dispersed particles, there is still a need for highly efficient systems comprising apparatus, methods and processes for efficiently separating small particles with only relatively low flow resistance, capital investment and maintenance costs, and which may if desired be fabricated in forms which conveniently handle large flow rates in comparatively small specific volumes. The present invention is aimed at fulfilling this need. In the development of the invention it was unexpectedly found useful for a variety of other applications involving translation of fluids with and without dispersed particles.

Objects of the Invention

A first object of this invention is to provide an improved process and apparatus for translating a fluid stream which may or may not contain dispersed particles.

A second object of this invention is to provide an improved process and apparatus for translating hydrodynamically at least a portion of solid and/or liquid particles contained in a liquid stream having a lower density than said particles.

A third object of this invention is to provide an improved process and apparatus for separating aerodynamically at least part of the condensable components of a fluid stream having multiple components.

A fourth object of this invention is to provide an improved process and apparatus for dispersing liquid aerosols in a fluid stream in order to cause physical and/or chemical reactions and then separating said aerosols.

Other objects and advantages of the invention will appear from the description which follows and from the attached drawings.

Summary of the Invention

The needs underlying the foregoing objects are fulfilled to varying extents and in various ways by several different aspects of the present invention. Among these are the following apparatus, method and process aspects which may be used singly or in any combination with each other.

One apparatus aspect of the invention includes apparatus for translation of fluid flowing along a flow path in a confined stream. This apparatus comprises at least one duct that has at least one inlet for receiving fluid, and at least one internal fluid enclosing surface. This surface defines an elongated fluid passageway, and substantially conforms along at least a substantial portion of its length to a geometric envelope formed by substantially congruent displacement of a planar figure. Such displacement occurs along a continuous generating line of finite length which has, at any point of at least a substantial portion of its length, substantial curvature and substantial torsion or twist. A reference point of the plane of said planar figure is retained on said generating line during said substantially congruent displacement. Also, the apparatus includes at least one outlet for discharge of fluid.

According to a preferred embodiment of the foregoing, the internal fluid enclosing surface has a center line which extends longitudinally in the duct. Within at least a

substantial portion of the length of the duct, this centerline is defined by the middle points of an infinite number of duct inner cross-sections in planes that are oriented to minimize the areas of the respective cross-sections. When viewed in a succession of said cross-sections at progressively and longitudinally advanced positions along a substantial portion of the length of said centerline, the fluid enclosing surface exhibits substantial variation of the aspect ratio of said cross-sections.

The preferred ducts are those for which the envelope is generated by displacement of a curved figure, most preferably a circular figure. Figures with other shapes may also be used with beneficial results, such as triangles, squares, rectangles, parallelograms, octagons, hexagons and other polygonal shapes, as well as portions of the foregoing and various irregular shapes.

A plurality of ducts formed with figures of any of the above shapes or other shapes, can be arranged advantageously in one or more clusters in which congruent ducts are closely adjacent laterally along substantial portions of their length, preferably in two or more directions. In such closely adjacent arrays the respective ducts may have walls with no substantial lateral spacing between them, including one or more walls which are distinct from or shared with other adjacent ducts, or may have walls which are spaced a short distance apart and are distinct walls, such as to provide for circulation of fluid about the exteriors of the ducts.

Clustering is exemplified by assemblies comprising arrays of plural ducts for conveying fluids, each of said ducts comprising confining walls of one or more component parts for confining and conveying said fluids. According to this aspect of the invention, the outer surfaces of the confining

walls of a plurality of said ducts have congruent portions of substantial length, the cross-sections and longitudinal profiles of which substantially coincide with or substantially fit within elongated generally helicoidal three-dimensional congruent envelopes. The ducts are clustered with said confining wall congruent portions closely adjacent one another laterally in two or more directions and along substantial portions of their respective lengths, and with at least said substantial portions extending in the same general direction.

In another example of clustering, the ducts have side or top and bottom walls which are an array of webs of undulating cross-section arranged in generally parallel, spaced apart relationship and having ridges and valleys in the surfaces thereof. The remaining walls of the ducts are formed of pluralities of spacers of undulating cross-section that are arranged generally parallel to one another in the spaces between said webs and perpendicular to said webs and to the ridges thereof. These spacers have margins with traces that conform to the surfaces of the webs and being secured in close fitting engagement with the web surfaces to form helical passageways.

An important improved process of particle translation may be performed in any suitable apparatus but presently appears to be best performed in the foregoing congruent translators. It is a method for twisting, pressure-reversal translation of fluid in a duct. It comprises causing said fluid to flow through the duct with a primary component of flow having a primary flow vector extending generally downstream in said duct. This primary flow may or may not be combined with a secondary component of flow and its corresponding vector which is transverse to said primary flow vector. This flow is caused to occur in a duct having confining walls and a centerline with both substantial twist and curvature

throughout a substantial portion of its length, and having a plurality of cross-sections along said portion of length. In accord with the invention the flow of fluid within said portion of the length of the confining walls is shaped to create a centrifugal acceleration field with a component generally transverse to the primary flow vector and to produce points of differing pressure across a given cross-section in an upstream portion of the duct. Among these points are spaced apart first and second points at which the pressures are at maximum and minimum values respectively and have a substantial positive or negative difference between them, which is referred to as a first difference. The method further includes causing the fluid to flow in said portion in the downstream direction from the given cross-section through additional cross-sections, the middle points of which define a flow path with a centerline having both substantial curvature and substantial twist, to reduce said pressure difference until it has reversed and has become a substantial difference of opposite sign in a downstream cross-section of the duct. Such reduction and sign reversal occur one or more times along traces extending downstream from the first and second points of the given cross-section through said additional cross-sections and follow vectors of the primary flow component forward from the first and second points through said additional cross-sections.

In another process aspect of the invention fluid is made to flow along a flow path in a confined stream in at least one duct that has at least one internal fluid enclosing surface. The fluid is caused to flow through an elongated fluid passageway that substantially conforms along at least a substantial portion of its length to a geometric envelope. This envelope has been formed by substantially congruent displacement of a planar figure along a continuous generating line of finite length which has, at all points on at least a substantial portion of its length, substantial curvature and

substantial torsion or twist. A reference point of the plane of said planar figure has been retained on said generating line during said substantially congruent displacement.

Another process aspect of the invention, that translates a fluid flowing in a confined stream, comprises establishing a primary flow composed at least in part of a plurality of substantially congruent primary streamlines in the fluid. The confined stream is conducted along an elongated flow path having a predetermined general direction of flow through successive cross-sections in planes perpendicular to said flow direction. A turning motion with substantial curvature and substantial torsion is induced in the primary streamlines for generating within at least a portion of the confined stream a centrifugal acceleration field with a substantially similar general direction in at least a portion of said cross-sections. The general direction of this centrifugal acceleration field is turned progressively between said cross-sections by an angle substantially similar to the torsion of the streamlines between said cross-sections.

Any of the preceding aspects may optionally but preferably be applied in applications in which the fluid contains dispersed particles and/or a source of dispersed particles, in which progressive turning of a centrifugal acceleration field between said cross-sections shapes a flow of said fluid and dispersed particles for subsequent centrifugal separation of said particles, and in which at least a substantial portion of the total mass of the dispersed particles that can be separated from the flow are subsequently separated centrifugally and collected.

Two additional process aspects of the invention are methods useful in both congruent and non-congruent helical duct separators. These methods improve the small particle collection efficiency of separators that have a threshold

particle size, the smallest particles which the separator can separate with nearly complete efficiency, e.g. at least 99%, from a dispersion of substantially uniformly sized particles. One method improves efficiency by controlling the proportions of above- and below-threshold particles in the separator, and the other traps below-threshold particles in a liquid layer on a wall in the duct. The two methods may be used separately or in combination.

In the first of these two methods, a fluid stream containing dispersed particles and/or a source of dispersed particles, including substantial quantities of particles above and below said threshold, is conducted in turbulent flow through a helical duct separator, and particles are separated from the stream. In the duct, the ratio of particles above and below said threshold is controlled to provide sufficient amounts, preferably an abundant supply, of particles above said threshold, to coalesce or agglomerate with the particles that are smaller than the threshold, and cause the smaller particles to be separated with the larger particles with which they have coalesced or agglomerated. In such a process, a major portion of the particles below the threshold size can be separated, even in a single pass through the separator. In one embodiment, a substantial quantity of relatively larger particles having a size above said threshold are introduced into or generated in the stream, during or prior to the flowing of the stream through the duct and prior to completion of particle separation. In another embodiment, the feed to the helical separator can be dispersed particle-containing fluid effluent from an upstream separator discharging the requisite proportions of particles of the required sizes. The foregoing measures can be combined, and other means of providing the particles in the required sizes and quantities may be used.

In the second of these two methods, a fluid stream containing dispersed particles and/or a source of dispersed particles, including substantial quantities of particles below said threshold, is conducted in turbulent flow through a helical duct separator, and particles are separated from the stream in a separation zone. A layer of liquid is provided upon a wall in the helical duct, in or upstream of the separation zone, and is caused to flow downstream in the duct in the same general direction as the fluid stream. A substantial portion of the particles below the threshold are brought into contact with and caused to coalesce with the liquid layer, and such particles are then separated from the stream with the liquid layer. In such a process, a substantially increased proportion of the particles below the threshold size can be separated, as compared to operation without the liquid layer.

The foregoing summarizes what are believed to be the principal aspects of the present invention. However, it should be understood that all new and non-obvious combinations of the subject matter disclosed in the present disclosure are considered to be part of the present invention.

Advantages

Various embodiments of the process and apparatus according to the invention result in one or more of the following advantages over prior art translators:

- Head losses in the fluid to be treated can be kept quite low, by reduction of parasitic secondary motion and the head loss coefficient, and by shortening the length of the flow path required for treatment of the fluid and its contents.
- Reduced head losses can be realized during an operation requiring translation of a fluid, either with enhanced

efficiency, or at least without unacceptable efficiency losses resulting from translation.

- In terms of throughput per unit volume occupied, the invention can attain a much higher level of throughput than is possible in known helical coil devices of similar cross-section, by minimizing wasted space between ducts and by permitting a higher velocity flow within the translator for a given head loss.
- These high throughput capabilities make it possible to design translators that are extremely compact.
- At a given primary motion velocity, a centrifugal acceleration field of high average intensity can be generated within a flowing fluid, thus promoting centrifugation of particles to be treated in the fluid.
- Since the apparatus for practicing the invention can be extremely simple and inexpensive to fabricate and assemble, as well as very compact, its capital cost can be moderate, leading to a very short pay-back interval.
- The apparatus for practicing the invention can also be extremely simple and inexpensive to operate and maintain, leading to low operating costs.

Compared with known processes and apparatus for aerodynamic or hydrodynamic separation, the process and apparatus of the invention exhibit one or more of the following advantages:

- At a given primary motion velocity, generation of a centrifugal acceleration field of high average intensity within a flowing fluid can promote centrifugation of particles to be separated from the fluid.
- Generation of congruent streamlines can limit parasitic secondary motion and thus the head loss coefficient.
- Effective centrifugation, can shorten the length of the required flow path in a separator.
- Success in limiting the head loss coefficient, when combined with shortening the length of the required flow path in the separator, can reduce total head loss.

- Because the invention requires expenditure of only a relatively moderate amount of energy beyond that theoretically needed for the separation work, the operating costs of the invention can be quite low compared to other known separation methods.
- Effective centrifugation, when combined with coalescence of particles within the translator, can make it possible to separate very small droplets and other particles from flowing fluids.
- Efficient separation of sub-micron particles from fluids with a low total head loss can facilitate compliance with environmental regulations that were previously difficult or impossible to satisfy economically.

Other advantages of the invention will be apparent from the description which follows, from the utilization of the invention and from combination of information thus gained with knowledge possessed by persons skilled in the art.

Brief Description of the Drawings

Figure 1 is a schematic diagram, in perspective, illustrating formation of a geometric envelope by congruent displacement of a figure along a helical generating line through a single turn about a longitudinal axis.

Figure 2 is a schematic diagram in a plane perpendicular to the axis of Figure 1, containing projections of the figure displaced in Figure 1.

Figure 3 is an end view, from the same position as in Figure 2, of a duct with inner and outer surfaces conforming to the envelope of Figure 1.

Figure 4 is a perspective view of the duct of Figure 3, taken from the same perspective as in Figure 1.

Figures 5 and 6 are schematic diagrams taken from the top and side respectively of a duct formed by congruent displacement of a figure along a generating line, the top and side walls being removed from the respective views to show the interior of the duct.

Figure 7A is a view similar to Figure 2, of projections of a figure of varying size displaced along the generating line of Figure 1, illustrating modified scale congruent displacement of a square figure.

Figures 7B through 7M are schematic diagrams in plan view of examples of figures with different shapes that can be substituted for the square figure of Figures 1-4 and displaced by congruent displacement, including modified scale congruent displacement, to form ducts corresponding to or useful in the present invention.

Figure 7N is a perspective view of a duct similar to that shown in Figure 3, but generated by congruent displacement of a hexagonal figure.

Figures 8A-D and 9A-D are two series of schematic diagrams, taken from similar points of view for comparison purposes, respectively showing congruent and non-congruent helical tubes of circular cross-section, plus their similarities and important differences. In each series the "A" Figures (e.g., Figures 8A and 9A) are developed views, shown in perspective, including a helical duct centerline about an axis and a series of duct cross-sections in planes perpendicular to that axis, these views being generally similar to Figure 1. The "B" Figures present the same cross-sections shown in the "A" Figures, but here they are projected on a plane perpendicular to the axis in a manner similar to Figure 2. The "C" Figures show, from top to bottom, top and side views of ducts conforming to envelopes

defined by the cross-sections of the A & B Figures, and a series of schematic representations of planes corresponding to the Figure "A" cross-sections. The "D" Figures represent different cross-sections of the tubes, those "seen" by the flow, which are taken in planes oriented to minimize the area of the cross-sections and which include middle-points shown in the "C" figures.

Figure 10 is a truncated schematic diagram in perspective and partially broken out showing a particle separator comprising congruent, circular cross-section tubes that are similar to those illustrated in Figures 8A-D.

Figure 11 is a truncated schematic cross-section in a plane which includes the central axis of a cylindrical heat exchanger housing containing congruent tubes of circular cross-section similar to those of Figure 10 but clustered in a pattern which includes spaces between the tubes.

Figure 12 is a transverse cross-section taken on section line 12-12 of Figure 10.

Figure 13 is an end view of a clustered array of congruent ducts identical to the one shown in Figure 3.

Figure 14 is a developed schematic view in perspective showing, from left to right, corrugated sheet material, a corrugated spacer cut from said material and having both marginal and surface undulations, and a projection of said spacer onto a plane to show its marginal traces.

Figure 15A is a schematic diagram, in perspective, with portions broken out and other portions shown in phantom, of a fluid translator formed with corrugated spacers like that shown in Figure 14, interspersed among corrugated plates, and Figures 15B and 15C are traces, in the same rectangular

three-coordinate system, of preferred spacers and plates for the Figure 15A embodiment.

Figure 16 is a perspective view of a stackable corrugated plate having both lateral and vertical undulations.

Figure 17 is a schematic diagram of the edges of two stacked corrugated plates like that shown in Figure 16.

Figure 18 is a schematic view of the edges of three stacked plates having bi-directional undulation (not shown) similar to that of Figure 16 but with a shape yielding ducts of hexagonal cross-section.

Figure 19 is a schematic view of the edges of four stacked bi-directionally undulating plates that yield ducts of generally circular cross section.

Figure 20 is a view similar to Figure 19, to which has been added fillets to round out the interior surfaces of the ducts.

Figure 21 is a schematic projection of a separator duct including three portions: first and second portions for shaping the flow of a stream of gaseous mixture into a strong swirling secondary flow which causes centrifugal separation of a major portion of a mass of dispersed particles in a third portion of the separator duct.

Figure 22 is a schematic projection of a separator duct for separating, in liquid form, a portion of the condensable vapor contained in a gaseous mixture.

Figure 23 is a schematic projection of a separator duct for atomizing liquid into a fluid mixture, fractionating the resultant droplets to smaller size in the fluid mixture and

then causing the smaller droplets to interact physically and/or chemically with the fluid mixture before being separated therefrom.

Figures 24A and 24B are respectively schematic diagrams of cross-sections in planes perpendicular to the central axis and flow cross-sections of a duct which presently appears to be the best mode for practicing the invention.

Figure 25 is a sample separation efficiency graph for a congruent separator duct of the present invention.

Best and Various Modes for Carrying Out the Invention

Figures 1-6

Figure 1 exemplifies generation of a congruent geometric envelope using a continuous generating line, at least a portion of which has substantial curvature and twist. The curved and twisted portion of the generating line may take a variety of forms, including a portion of an helix or pseudo-helix or an helico-spiral or a pseudo helico-spiral, as well as non-helical forms.

In this embodiment, generating line 10 is preferably a regular helix having radius R, pitch 2(PI)p and longitudinal axis 11. Circle 12, centered on and perpendicular to axis 11, is one of a series of similar circles included in the outer surface of an imaginary cylinder which also includes generating line 10. Circle 12 and a similar circle 13 also delineate the ends of a single turn 14 of generating line 10 about axis 11.

For purposes of this embodiment, circle 12 is in and therefore represents the location and orientation of a reference plane which in this case marks the beginning of the displacement of square figure 15 along generating line 10.

Square figure 15 has four sides terminated and identified by its respective corners A,B,C,D. The figure 15 is included in a three-dimensional coordinate system having center O and X, Y and Z axes O_x,O_y,O_z. For purposes of the present embodiment, corner A of square 15 coincides with center O and sides AB and DA coincide with axes O_x and O_y, respectively. While the figure 15 is not required to be planar or to coincide with any of the axes of the coordinate system, in the present embodiment the corners B and D are points representing substantial values on the respective axes, while the point A represents a value of 0 on the axis O_z, whereby the figure 15 has three points each representing definite values in the coordinate system.

In the present embodiment, the square 15 is perpendicular to axis 11 of helix 10, and coordinate system O_x,O_y,O_z has two of its axes, O_x,O_y within the reference plane coinciding with circle 12, while axis O_z is perpendicular to that plane. It should be understood that it is also within the scope of the invention for two or three of the axes of the coordinate system of Figure 1 to be at an angle to said plane when the figure 15 is in its starting position.

In strictly congruent translation of figure 15 along generating line 10, the figure 15 maintains a constant position within the coordinate system and the coordinate system is displaced along the generating line, keeping the coordinate system center O on the generating line and keeping the respective axes of the coordinate system, in its successive positions, parallel to the positions that those axes occupied at the beginning of the displacement. This is illustrated in Figure 1 by the parallelism between the axes O_x,O_y,O_z and O_x',O_y',O_z', the latter corresponding with the final position of the square figure 15 in the plane represented by circle 13. It will be appreciated that coordinate systems with axes similar to O_x,O_y,O_z can be drawn

for each of the positions of the figure 15 in Figure 1, and that in this strictly congruent embodiment the respective axes of all of those coordinate systems will be parallel with one another, just as O_x, O_y, O_z and O_x', O_y', O_z' are parallel.

All of the respective positions of square figure 15 shown in Figure 1 are shown in end view in Figure 2. This view shows circle 12, which coincides with the projected trace of generating line 10, and shows the sides AB, BC, CD and DA on representative square figures 15. In the present embodiment, with the type of congruent displacement shown in Figure 1, the corners A,B,C,D of closed figure 15 have individual centers of rotation 16, 17, 18 and 19, respectively. When the limited number of closed figures 15 between circles 12 and 13 is replaced by an infinite number of such figures arranged along generating line 10 in the same manner as those shown, the result is an imaginary congruent envelope reflecting the curvature and twist of the generating line and the length over which the figure has been displaced on that generating line.

When a duct 23 is fabricated having walls, inner surfaces and/or outer surfaces substantially coinciding with such an envelope, one or more of the above-mentioned advantages follow. An end view of such a duct is provided in Figure 3, and consideration of that Figure in connection with the distinct centers of rotation 16-19 of the square figure which generated the envelope, will show why the horizontal and vertical external surfaces 24-27 of duct 23 respectively remain horizontal and vertical at the top, bottom, right side and left side of the duct as it continues through a complete turn represented in Figure 3. As the walls of the duct are formed in this case of sheet material of congruent cross-section, the configurations of the interior surfaces are similar to those of the exterior surfaces. The duct 3 is shown in perspective in Figure 4.

Using helical and non-helical generating lines with portions having substantial curvature and substantial twist, one can prepare a wide variety of ducts with or without regular turns, representing a substantial fraction or an integer or non-integer multiple of a complete turn, and optionally including non-curved portions. For example, Figures 5 and 6 show a continuous, single piece duct 29 having inlet and outlet portions 30,31 and a central portion marked off by six references lines 32-37 into five duct sections 38-42. Duct 29 is formed by congruent displacement (not shown) of a square figure (not shown) similar to square 15 of Figures 1 and 2 along five turns of a continuous generating line (not shown) that has an axis horizontal and parallel to the plane of the drawing with both straight and curved segments to provide the duct inlet and outlet portions 30,31 with curved and straight portions 43,44 that permit entry and exit of fluid into and from the duct sections 32-37 without an abrupt change of direction. The helical segments of the generating line generate duct section 38-42 each representing five complete helical duct turns that are similar in principle to the duct illustrated in Figures 3 and 4.

In Figures 5 and 6 the top and side walls have been removed from the respective views to show the interior of the duct. Thus, the top view of Figure 5 shows a projection of the horizontal internal bottom surface of the duct, the borderlines of this projection being the projections of its vertical sides. The side view of Figure 6 shows one of the vertical sides in a projected form, its borderlines being the projections of the horizontal sides.

Figures 7A-7N

As shown by Figures 1-2, it is preferred to base the shape of a congruent duct on strictly congruent displacement of a figure of constant area and shape, held in fixed reference to

its coordinate system, the system coordinates being held parallel to their prior positions as the system is displaced along a generating line. However, this is not essential.

See for instance the definition of "congruent" given below, and especially the definition of "modified scale congruent displacement." An illustration of this is provided in Figure 7A which is similar to Figure 2 in showing generating line 10 and square figure 15. A number of additional square figures 47-53 are arranged about the circular projection of generating line 10, there being a smaller number of such figures in this view to facilitate illustration of the fact that the size of the square varies from a maximum represented by square 15 through progressively smaller sized figures 47-49 to a minimum represented by square 50 and then increases in squares 51-53 back to a maximum similar to the square 15. Note that as signified by the reference characters A,B,C,D, although the sizes of the squares change, their top, right side, bottom and left sides retain their respective positions relative to any selected reference plane (not shown) during displacement along generating line 10, thereby imparting a congruent character to the resulting imaginary envelope and ducts fabricated to conform therewith.

As shown by Figures 7B-7N, replacement of figure 15 with figures of other shapes can provide a basis for forming geometric envelopes and congruent ducts of different cross-sections. The figures respectively show such exemplary replacements as rectangle 57, parallelogram 58, diamond 59, trapezoid 60 and several quasi-rectangles, including a first one 61 having a corner removed, another 62 with a sloping top, still another 63 with a wave-form top, yet another 64 with wave-form top and bottom, and another 65 with convex and concave curved sides. Other useful closed figures include triangle 66, oval 67, a quasi-hexagon 68 with two lengthened opposed sides. A duct 69 conforming at its inner and outer

surfaces with a geometric envelope formed by congruent displacement of a regular hexagon is shown in Figure 7N.

Within limits indicated by the definition of "Congruent," given below, strictly congruent displacement of the figure which generates the geometric envelope and related duct surfaces is not required. As the definition shows, the invention contemplates substantially congruent ducts that are not strictly congruent but take various forms which result in substantial attainment of one or more desired performance characteristics.

For example, during displacement, there may be progressive or alternating deviations of the position of the closed figure in its coordinate system. This may for instance take a form in which the figure moves within the coordinate system during displacement, so that certain points on the figure move from their original position(s) in one or more coordinates. Each such deviation may progress in a single direction, but one or more forms of alternating deviation including motion of the point(s) back and forth through and to either side of their original coordinates is possible.

By way of illustration, visualize displacement of the coordinate system containing figure 15 of Figures 1-2 being displaced with a clockwise motion in the manner previously discussed, and then impose on this motion counter-clockwise motion of corners B and D about point A through a range of a few from their starting positions on their respective coordinates O_x and O_y. As another example, one can also impose on the above-described generally clockwise displacement motion a rocking of the square figure about its side AB on coordinate O_x so that it rocks back and forth through the plane of coordinates O_x,O_y. Imposition of other simple and complex motions is possible, consistent with the definition given.

Similar results can be obtained if the figure which generates the geometric envelope and related duct surfaces is held in fixed reference to its coordinate system, and the coordinate axes of the latter undergo progressive or alternating deviations from parallelism with their prior positions. Other deviations from strictly congruent ducts are acceptable.

<u>Figures 8A-9D</u>

This invention is an improvement on fluid translation systems that generate curved and twisted streamlines in a flowing fluid to create centrifugal acceleration fields that in turn produce pressure gradients in the fluid. The known systems of this type are usually but not always helically coiled ducts or portions thereof, which generate a primary flow with curved and twisted streamlines of generally helical shape along a generally helical flowpath.

In a curved and twisted duct, the flowpath may for the sake of analysis be viewed as having an infinite number of flow cross-sections distributed along its length. Such flow cross-sections are, for purposes of the present discussion, taken in planes oriented in a way that minimizes the area of each section.

Prior helically coiled ducts generally have a unique helix axis, but they may also have several axes which differ from one cross-section to another cross-section of the duct. Even if the duct does not have a helix axis that is unique for all of its cross-sections, the primary flow streamlines which are most distant from the axis of a given cross-section of the flowpath continue to be the most distant from the axis in each of the downstream cross-sections of the flow path. The behavior of the primary streamlines nearer the axis of the given cross-section is analogous. These remain less distant

from the axis in each of the following cross-sections of the flowpath.

A centrifugal acceleration field usually has a characteristic direction in each of its successive cross-sections. In general, that direction extends from the streamlines nearest the axis to those most distant from it. The varying pressures generated by such a field in a given cross-section are lowest among the former streamlines and highest among the latter streamlines, while the resultant pressure difference exhibits a constant sign as the fluid progresses through additional cross-sections along its flowpath.

In contrast, using generally congruent ducts and flowpaths or other suitable means, the present invention can cause a primary streamline that is among those most distant from the axis to become less distant from the axis as flow progresses along the flowpath, and vice versa. Therefore, a pressure difference generated by the centrifugal acceleration field between streamlines of local higher pressure and streamlines of local lower pressure in a given cross-section can be made to progressively vanish and then reappear with an opposite sign as the fluid progresses along its flowpath through additional cross-sections. With repetition of these pressure difference reversals in successive cross-sections, an oscillating character may be imparted to the pressure of each primary streamline as it flows along the flowpath.

By imparting an oscillating pressure characteristic to the flow, the invention makes it possible to inhibit or suppress the tendency, present in prior helical tube separators and in other devices that generate curved streams, to induce secondary flows in the flowing fluid, which may be in the form of pairs of counter-rotating vortices or of simple vortices (swirls). Because a congruent duct can operate with

reduced secondary flow, its pressure loss coefficient is smaller than that of a corresponding prior art helical duct.

When the invention is employed to produce a flow with generally congruent streamlines, the centrifugal acceleration field can be more uniform and closer to its theoretical maximum value in its successive cross-sections than it would be in prior art helical coils. The direction of this field rotates in the successive cross-sections due to the twist of the streamlines. When particles are present in the flowing stream, the combination of this rotation and of the oscillating position of the primary streamlines in the duct and flowpath result in an oscillating motion of the particles relative to said fluid. Such motion, driven by centrifugal accelerations which can be several hundred times the acceleration of gravity, is quite useful for enhancing physical and/or chemical reactions between the particles and the surrounding fluid.

Figures 8A-8D and 9A-9D are two sets of comparison figures intended to illustrate some of the above similarities and fundamental differences of congruent and non-congruent helical ducts of circular cross-section, inasmuch as ducts formed by congruent displacement of a circumference and especially a circular figure are preferred for what are presently thought to be the most important applications of the present invention. Thus, Figure 8A includes generating line 10, axis 11 and circles 12,13 of figure 1, representing one complete turn of the helical generating line, and perfect circle 15, identified in five of its positions by reference numerals 73-77.

It should be noted that generating line 10 has an angle which remains either positive or negative with respect to the plane of the generating figure 15 throughout a substantial portion of the length of the congruent duct. Thus the component of

the tangent of this angle which is perpendicular to the plane of the generating figure keeps the same sign (+/-) and does not become 0 and change sign.

While coordinate axes have not been shown for the respective positions of the circular figure 15, the reader will readily understand that each example of the circular figure shown in Figure 8A has a coordinate system O_x, O_y, O_z similar to that shown in Figure 1, except that the centers 78-82 of the circular figures coincide with the generating line 10 and with the center of the coordinate system. Here again, the axes of the coordinate system are maintained parallel to one another in the displacement of the circular closed figure through its respective positions 73-77 and the remaining positions in the direction of circle 13.

Figure 8B shows a projection of the circular figure in its respective positions 73-77 and in this respect is similar to a portion of Figure 2. Note that Figure 8B shows the projections of respective center positions 78-82 of the circular figure coinciding with the projection of generating line 10, and that the circular figure in its respective positions coincides with curves 84 and 85 respectively, indicating an inner and outer radius of the resultant envelope.

As the circular closed figure does not have identifiable corners similar to those identified as A,B,C,D in Figure 2, the circular figure has been provided with reference characters W1-W5, all of which identify the position of a specified point on the circular figure as it moves through its positions 73-77. Reference characters X1-X5 identify a diametrically opposite point on the circular figure in the same series of positions. The intent of reference characters W1-W5 and X1-X5 is to show that the circular figure does not

rotate about its center as it is displaced along the generating line.

The respective series of reference characters W1-W5 and X1-X5 may also be considered to represent sample traces of primary streamlines in any level of turbulence which may occur in the separators and other translators of the present invention, including high, low and moderate levels of turbulence. Turbulence is generally accepted to have a sufficiently small impact to be ignored when considering macroscopic aspects (or statistical averages) of flow, such as streamlines, velocity repartition, pressure, and so forth. Thus, flow defined in terms of streamline charcteristics in turbulent flow conditions is a scientifically founded concept which can be observed and measured by well defined scientific methods.

Reference characters W1-W5 and X1-X5 illustrate how the present invention can cause the above-mentioned pressure difference that progressively vanishes and then reappears with an opposite sign as the fluid progresses along its flowpath through a series of cross-sections, whereby an oscillating character may be imparted to the pressure of each primary streamline as it flows along the flowpath. As shown by W1-W5 and X1-X5, a primary streamline which is on the duct inner wall and which is among those most distant from the axis 11 becomes less distant from the axis as flow progresses along the flowpath, and vice versa. Also, consider the fact that, due to the centrifugal field, the outer largest circle shown is the locus of all the points where the pressure level is the highest, while the inner circle is the locus of all the points where the pressure level is the smallest. Applying these observations to the points W1 through W5, one can appreciate that the pressure will be the highest in position W1 and progressively reduce in successive positions W2, W3, W4 to reach its lowest level at W5. For point X, the pressure is at its minimum at position X1 and increases

gradually to a maximum at position X5. The continuing and alternating nature of these changes as the flow progresses downstraem is the source of the afore-mentioned pressure reversal.

Figure 8C respectively discloses a top view, side view and several reference lines pertaining to a duct conforming to the envelope illustrated by Figures 8A and 8B. This duct has left and right ends 87 and 88, and the reference traces 89-93 respectively coincide with the positions of corresponding planes which are parallel to the reference plane and which contain centers 78-82. R_h indicates the helix radius. Cross-sections through duct 86 in planes perpendicular to axis 11 at locations corresponding with centers 78-82 will have the appearance of circles corresponding to those shown in Figure 8B. However, the flow cross-sections of the duct, as "seen" by fluid flowing in it, are quite different, as illustrated by Figure 8D, and do not correspond with the circular cross-sections shown in Figure 8B. Rather, the flow cross-section is best defined as that cross-section which is produced by a plane cutting through the tube in such a way as to minimize the area of the resulting cross-section. Such a cross-section is difficult to depict in a two-dimensional medium, but the approximate shapes of the flow cross-sections at centers 78-82 are illustrated in Figure 8D.

It should be understood that the cross-sections shown in Figure 8D are somewhat idealized. The true shapes of these cross-sections are egg-shaped to a very slight or very noticeable degree depending on the ratio between the radius of the helix and the radius of the circular figure which is displaced from the congruent duct. If this ratio is very large, the accompanying drawings represent a close approximation of the reality. On the other hand, if to the contrary this ratio is not much higher than one, the actual

shape of these figures would have a rather pronounced egg-shape.

The internal fluid enclosing surface of duct 86 has a center line which extends longitudinally in the duct, and is defined by the middle points of an infinite number of duct inner cross-sections that are oriented to minimize their respective areas, as shown in Figure 8D. As that figure shows, when a succession of said cross-sections is viewed at progressively and longitudinally advanced positions along a substantial portion of the length of said centerline, the internal fluid enclosing surface exhibits substantial variation of the aspect ratio of said cross-sections.

The foregoing characteristics of systems according to the invention can be employed alone or in combination with other known properties of prior art helical coils. For instance, these include the tendency of larger drops to split as they impact with the tube wall and to re-entrain in the flowing fluid, and the tendency of smaller drops captured by the wall of the duct not to re-entrain.

Compare the foregoing congruent duct of Figures 8A-8D with a non-congruent but otherwise similar helical duct shown in related Figures 9A-9D. The non-congruent duct is typically formed by winding a tube along a helical generating line on the surface of a mandrel, and results in the formation of distinctively different cross-sections. Thus, Figure 9A shows the same generating line 10, axis 11 and circles 12 and 13 depicted in Figure 8A. From the foregoing, one can visualize a mandrel having a diameter equal to the diameter of the circles 12,13 less the diameter of the duct, a length corresponding to the distance between these circles and a helical generating line extending along the surface of the mandrel between its ends.

When a tube of circular cross-section is wound on such a mandrel along a helical curve at a significant angle to the axis of the mandrel (for example 45 degrees), there is a slight flattening of the tube. This can be suppressed by known procedures and will be ignored for purposes of this discussion. During winding, the tube twists once about its own centerline for each turn about the mandrel. The resultant duct 111 is shown in Figure 9C, has helix radius Rh, left and right ends 112 and 113, and superficially resembles congruent duct 86 of Figure 8C.

Figure 9D shows a series of flow cross-sections of the non-congruent duct of Figure 9C, taken in a manner similar to that employed in Figure 8D, in planes oriented to minimize the areas of the cross-sections. These flow cross-sections include centers 103-107 corresponding to centers 78-82 of Figures 8A-8D, and reflect the circular nature of the duct. All these circles have the same aspect ratio, which is in contrast to the elliptical type flow cross-sections of the congruent duct shown in Figure 8D.

Thus, as shown in Figures 9A and 9B, cross-sections 98-102, taken perpendicular to axis 11 in planes indicated by traces 114-118 of Figure 9C, reveal irregular ovals dissimilar to the corresponding circular cross-sections 73-77 of Figure 8B. The oval cross-sections of Figure 9B are confined between circles 109 and 110, representing the inner and outer radii of the resultant helix. In this non-congruent duct, formed with rotation of the tube about its own centerline during winding, points W1-W5 of the irregular oval cross-sections remain on the outer radius curve 110, while the points X1-X5 remain on inner radius curve 109. This non-congruent tube will not therefore produce the pressure reversal phenomenon discussed above.

A non-congruent helical coil of this type is capable of producing, in addition to a primary flow, a secondary flow composed of two counter-rotating vortices. Although such secondary flow can contribute to the separation of aerosols, it is much too weak for efficient separation of particles well below 1 micron in size. Thus, when the present invention utilizes a congruent duct to produce a fluid flow with congruent primary streamlines, this small contribution is lost but can be more than fully compensated for by other advantages of the invention, which afford opportunities to shorten the length of the separator duct and reduce head losses, thereby recovering the lost contribution to separation efficiency, and to make better use of the volume available through stackability.

<u>Figure 10</u>

A preferred application of the translators of the present invention is in aerodynamic or hydrodynamic separator apparatus and processes for separating dispersed particles from fluid flowing along a flow path in a confined stream. Each of several forms of translators disclosed herein may be employed as separators.

According to a preferred embodiment of the invention comprising separator systems, the duct of the separator comprises a separation zone having an internal wall for confining a fluid stream. The wall includes a first portion for inducing a turning motion with substantial curvature and substantial torsion in a plurality of substantially congruent streamlines of a primary flow of said fluid for generating a centrifugal acceleration field within at least a portion of the confined stream. This acceleration field has a substantially similar general direction in at least a portion of each of its cross-sections by a plane parallel to the plane of the above-mentioned closed figure. This acceleration field exerts force on said particles in said

general direction and turns progressively, as the flow moves downstream through said cross-sections, by an angle substantially similar to the torsion angle of the streamlines between said cross-sections. The duct also comprises means for collecting the particles from this zone.

The above-identified duct wall may include a second portion for accumulating sufficient turning motion of the primary flow in the confined stream for causing at least a substantial portion of the total mass of the dispersed particles and/or of the source of dispersed particles that can be separated from the stream to migrate from major portions of said primary flow under the influence of the centrifugal force, toward a predetermined peripheral zone of the duct and to form a particle-rich portion of the primary flow within this zone.

According to another embodiment, the centrifugal acceleration field causes the dispersed particles to move within the confined fluid stream and relative to it in the general direction of said force, thus creating in said confined stream enriched regions having a relatively higher quantity of said particles and depleted regions having a relatively lesser quantity of said particles. These regions develop at least near portions of the boundaries of the confined stream. The turning of said acceleration field also causes these denser and thinner regions to move similarly to the turning of said field within said confined stream along said flow path. They create thus at least near the boundaries of these stream zones of fluid a secondary flow having a rotational velocity substantially equal to the rotational velocity of the general direction of the centrifugal acceleration field.

In a further embodiment of the invention, the duct wall can include a first portion for generating a secondary flow in

the primary flow of said confined stream with said turning motion. This secondary flow comprises a swirl having substantial components of rotational velocity transverse to the flow path. The wall has a second portion for accumulating sufficient turning motion of the primary flow in the confined stream for causing at least a substantial portion of the total mass of the dispersed particles that can be separated from the stream to migrate from major portions of the primary flow under the influence of centrifugal force, generated at least partially and substantially by said secondary flow, toward a predetermined zone of said duct and to form a particle-rich portion of said primary flow within said zone.

As will be explained in greater detail in connection with Figure 21 below, variation of the inner cross-sectional shape and/or area of the duct can be used to cause an increase of the rotational velocity of the centrifugal acceleration field as the fluid flow progresses along its pathway.

Another embodiment the invention includes a process for aerodynamic or hydrodynamic separation of components from a fluid, comprising: (A) establishing a primary flow composed of a plurality of substantially congruent primary streamlines in a confined stream, containing dispersed particles and/or a source of dispersed particles, of a fluid flowing along an elongated flow path having along its full length a general direction of flow; (B) inducing within said confined stream, along at least a portion of said flow path, a turning motion of said primary streamlines including substantially similar curvature and torsion among said streamlines, for generating a centrifugal acceleration field having a substantially similar general field direction in at least a portion of each of its cross-sections by planes perpendicular to said general flow direction; (C) causing the general direction of the centrifugal acceleration field to turn progressively as the

flow passes between said cross-sections by an angle substantially similar to the torsion angle of the streamlines between said cross-sections, thus shaping the flow for subsequent centrifugal separation of said dispersed particles; and (D) subsequently separating centrifugally and collecting at least a substantial portion of the total mass of the dispersed particles that can be separated from the flow.

In another embodiment, the process comprises: accumulating sufficient turning motion of the primary flow in said confined stream for causing at least a substantial portion of the total mass of the dispersed particles and/or of the source of dispersed particles that can be separated from the stream to migrate from major portions of said primary flow under the influence of said centrifugal force, toward a predetermined peripheral zone of said duct and to form a particle-rich portion of said primary flow within said zone.

In another embodiment, the process comprises: continuing said turning motion for causing the centrifugal force induced by said acceleration field in said dispersed particles to move said dispersed particles within said confined fluid stream in the general direction of said force, thus creating in said confined stream denser regions enriched in at least a portion of said particles and thinner regions depleted in at least a portion of said particles, said regions developing at least near portions of the boundaries of said confined stream; causing said turning of the field of said centrifugal force to move said denser and said thinner regions similarly to the turning of said field within said confined stream along said flow path, thus creating at least near the boundaries of said stream zones of fluid a secondary flow having a rotational velocity substantially equal to the rotational velocity of said general direction of said centrifugal acceleration field.

In another embodiment, the process comprises: establishing a primary flow of a fluid flowing along a flow path in a confined stream containing dispersed particles and/or a source of dispersed particles; inducing a turning motion in said primary flow for generating in said confined stream a secondary flow comprising a swirl having substantial components of rotational velocity transverse to said flow path; and accumulating sufficient turning motion of the primary and secondary flow in said confinement member through a substantial total angular interval for causing at least a substantial portion of the total mass of the dispersed particles and/or of the source of dispersed particles that can be separated from the stream to migrate from major portions of said confined stream under the influence of centrifugal force, generated at least partially and substantially by said secondary flow, toward a predetermined zone of said confinement member and to form a particle-rich portion of said primary flow within said zone.

In another embodiment, the process comprises: causing the general magnitude of said centrifugal acceleration field and/or its rotational velocity to increase while the fluid flow progresses along its path.

In another embodiment of the process, the cross-section of the confined stream by a plane perpendicular to said general direction of flow is substantially circular.

In another embodiment of the process, the outer shape of the confined stream in substantial portions of said stream is generated by the substantially congruent displacement of a planar closed figure perpendicular to said general direction of flow along a line having substantially the shape of an helix or a pseudo-helix or an helico-spiral or a pseudo-helico-spiral having an axis parallel to said general

direction of flow, a reference point of the plane of said closed line being retained on said generating line during said substantially congruent displacement.

In another embodiment the process comprises: establishing said primary flow with a fluid containing dispersed particles or a source of dispersed particles, including particles of about two microns or less in particle size that can be separated from the stream; accumulating sufficient turning motion of the primary flow in said confined stream through a total angular interval of at least about 720 degrees while continuing downstream along said flow path and for causing at least 90% of all particles having a particle size in the range of about 1.5 to about 2.5 microns, or about 0.75 to about 1.25 microns, or about 0.35 to about 0.65 microns, to migrate from said stream under the influence of said centrifugal force toward said predetermined zone, and recovering said particles.

In the process and apparatus according to the invention, the flowing fluid stream having been progressively de-homogenized in particles to be separated, the layer more enriched in said particles may be skimmed by means which derive said layer, thus separating it from the main stream, of which it represents a small fraction. This derived stream then undergoes, for instance in a decanting or extracting chamber, separation of the particulate components it contains, and is then either sent back for recycling in an appropriate point of the main circuit located upstream or at the beginning of the zone of processing the fluid stream, or used for any other purpose. When the particles to be separated are liquid, the liquid stream resulting from the separation may be extracted, as a variant, without being accompanied by a derived stream, for instance by porous walls or in a settling reservoir.

An embodiment of a preferred form of separator 123 according to the invention is disclosed in Figure 10. It has a cylindrical casing 124 having upper and lower flanges 125,126 to which are attached end cap 127 and hopper 128. A fluid inlet 131 for fluid having particles dispersed therein enters through the cylindrical wall of casing 124 into a plenum 132 defined by end cap 127, the adjacent walls of casing 124 and an upper tube support plate 133. A plurality of congruent tubes are clustered in a contiguous array, have their tops flush with the upper surface of plate 133 and are secured in gas tight relationship with the plate so that fluid pressure extisting in plenum 132 can be relieved only by passage of the fluid and particles into the tubes 134. These ducts have inner and outer surfaces in substantial conformity with geometric envelopes generated by a congruent displacement of a circular figure along an at least partially helical generating line. These ducts may preferably have outlines in their side and top views which are similar to the duct of Figures 5-6, or may resemble the ducts described in Figures 8A-8D. The array of tubes passes through one or more supports, such as intermediate support plate 135 in the central portion of casing 124, and pass, in gas tight relationship, through lower tube support plate 136, so that the downstream ends of the tubes open into collection chamber 137.

In the tubes 134 of the Figure 10 separator, the course followed by the primary component of the streamlines of the fluid stream is controlled by the shapes of the inner surfaces of the ducts. These courses include curves substantially congruent to the generating curve from which the inner surfaces of the ducts were generated. Because substantial portions if not all of the lengths of the tubes were generated from curves including helical portions, the primary components of the flowpaths of the streamlines are

substantially congruent helices while traversing the cross-sections of the helical portions of the ducts.

At many, preferably most, or more preferably substantially all of these cross-sections in the respective ducts, the primary streamlines distributed across the major portions of the areas of the cross-sections have substantially the same curvature and substantially the same torsion. Where their velocities are substantially similar, i.e. within the bulk of the flowing stream in which the velocity profile in turbulent flow is fairly flat, these streamlines generate centrifugal acceleration fields in these areas. In the bulk of each of these cross-sections of a given duct, which cross-sections are in planes perpendicular to the helix axis, the acceleration field is substantially uniform in direction and magnitude. Due to the helical shape of the primary streamlines and their congruency, the direction of the centrifugal acceleration field is caused to turn progressively between said cross-sections by an angle substantially similar to the torsion angle of the streamlines between said cross-sections.

Particles dispersed within fluid in the respective ducts are thus subjected to a primary motion centrifugal acceleration field. When their density is higher than that of the fluid, the particles are subject within the fluid to centrifugal force which causes them to move relative to the fluid stream in the direction of the field. Their velocity relative to the fluid depends on their size. Smaller particles having for instance submicron sizes move very slowly relative to the fluid, while larger particles having for instance sizes above one micron move less slowly relative to the flow, towards the internal wall of the duct.

Particles having a given density and an initial size equal to or larger than a threshold size at which their velocity

relative to the flowing fluid is sufficient to move them into the vicinity of the internal wall of the duct will either accumulate in a fluid-containing zone near the wall, or will rebound against the wall if their size is considerably larger than said threshold size. On rebounding, liquid particles split into smaller particles which are again projected by the centrifugal force against the wall and are again split, until their size is small enough to prevent their rebounding from the wall again. A simple theoretical treatment of droplet motion and capture in a two-dimensional bend where centrifugal force on the droplet is balanced by the drag force can be found in BURKHOLZ, A., Air Pollution Control Part IV. Eds. Bragg and Strauss, Publ. Interscience, 1981.

Collisions occur between larger and smaller particles within the ducts because of differences in the relative velocities of the particles. To the extent the particles are coalescible, collisions cause coalescence to occur between them, causing the larger particles to sweep or gather up a very large portion of the smaller dispersed particles during their motion towards the walls of the duct. As a result, the separated particles, i.e. particles withdrawn by centrifugal force from the bulk of the fluid moving within the separator duct and concentrated at or near the inner wall of said duct, will include not only those particles having an initial size equal to or larger than the threshold size at which such separation takes place in the absence of coalescence, but also the mass of those smaller particles which are swept by and coalesced with the larger particles.

Separated particles accumulating in peripheral zones of the duct create in the confined stream enriched and depleted regions respectively containing relatively higher and lower quantities of said particles, said regions developing at least near portions of the boundaries of said confined stream. The turning of the field causes said enriched and

depleted regions to turn with a motion similar to that of the field, creating at least near the boundaries of the stream a secondary flow with a rotational velocity substantially equal to the rotational velocity of the general direction of the field. In conjunction with accumulation of sufficient turning motion of the confined stream, the centrifugal acceleration can cause at least a substantial portion of the total mass flow of those dispersed particles that can be separated from the stream to migrate from positions throughout the cross-section of the primary flow toward a predetermined peripheral zone of the duct and to form a particle-rich portion of the primary flow within that zone.

The resultant particle rich layer on or adjacent the fluid confining internal surfaces of tubes 134 may for instance be a moving layer of solid particles or a coherent layer of liquid. The particles thus separated and accumulated in the peripheral zones may be collected by added collecting means (not shown), for instance a skimmer. Other recovery devices may be provided in the duct to recover particles and/or fluid from peripheral and/or central zones of the duct, especially in downstream portions thereof. However, in certain preferred embodiments of the invention, when recovering coalescible particles of liquid and/or solids that migrate to the walls of the duct, recovery devices need not be present in the duct.

For example, it is an advantage of some preferred embodiments of the invention that liquid layers accumulated in peripheral zones can stream out of the open bottom ends of the tubes 134 and settle by gravity in the form large droplets into collection chamber 137. It acts as a settling reservoir from which the liquid may be recovered through recovered material outlet 139. The fluid from which the particles have been separated exits collection chamber 137 via fluid outlet 138.

If the particle rich layer formed in tubes 134 was composed of coalescible solid particles, including for instance solids that are not normally agglomerative but which have been rendered coalescible by their having been wetted by liquid particles also present in the tubes 134, the solid particles may also settle by gravity into collection chamber 137 and be recovered through recovered material outlet 139. However, if solid particles are entrained in the fluid exiting via outlet 138, such fluid may be recycled for a further pass through the above separator or passed to an additional separator of any suitable kind, including another separator as shown in Figure 10.

Persons skilled in the art will appreciate that a separator duct as described above, having an internal surface with a given set of dimensional and shape characteristics, will exhibit different separation efficiencies when operating on different fluids carrying particles differing by their nature, their size and their capacity of coalescence. To adapt the performance of the separator to the applications at hand, a number of parameters may be manipulated, including for instance the primary velocity at the inlets of tubes 134, sample velocities being given below. For best results, the velocity of the flowing fluid stream should be moderate upstream and downstream of the portion of the congruent duct in which separation takes place. Other parameters which can be varied in the design process include the shapes of the curve and of the figure. The shapes of the generating curve and figure used to generate the shape of the duct may both vary from one portion to another along the length of the duct, and an example of such variation is included in a description of a preferred embodiment below.

In a regular helical congruent duct, for each fluid medium that is well defined (based on its nature, temperature, pressure, state, density, coalescibility, viscosity, etc.)

and contains dispersed particles that are well defined (based on their nature, state, density, coalescibility, size repartition histogram, total specific load in the fluid, etc.), the separating cut point is a function of the velocity of the fluid, of the radius and pitch of the generating helix, of the shape and hydraulic diameter of the cross-sections, and of the number of turns of the helix.

Separation efficiency should be balanced against the head loss required for separation. A small head loss requires a small curvature, small torsion, and use of the shortest length that is sufficient for efficient separation. Thus one has to balance head loss with the radius and pitch of the helix and its number of turns.

Curvature and twist both contribute to separation. In general, both larger curvature and larger twist result in smaller length of the separator and in less pressure drop. However curvature is limited by the requirement of balancing it against the hydraulic radius of the duct. High curvatures require too small a diameter in the duct. Twist is limited by its action on the cross-sectional area of the flow passageway. When too high, twist results in too small passageway for any given generating closed planar figure.

Other parameters to consider in the design process are the direction of flow in the duct, the dimensions of the transverse cross-section of the flow path within the duct, the profile-in-length and length of the duct, the dimensional parameters of the helical portion of the generating curve, which may vary along the curve, and the desireability of avoiding amounts and forms of surface roughness that would substantially or seriously increase the pressure loss through the duct at its design flow rate.

The work absorbed by the process in the form of pressure losses in the fluid stream between the inlets and outlets of the ducts will be greater if the theoretical separation work is greater. In various embodiments of the invention, the congruent displacement method of generating the inner surface of the duct causes for any given primary velocity a maximal bulk centrifugation of the particles to be separated, while reducing parasitic pressure losses considerably. For instance, in the most preferred embodiments of the invention, no substantial secondary vortices develop within the flowing stream when no separable particles are present in the stream. Substantial secondary vortices, in the form of peripheral swirls, are created within the flowing fluid only by the accumulation of separating particles in peripheral regions of the confined stream. Although said secondary vortices do not affect substantially the head loss of the bulk of the flowing stream, they facilitate migration of separating particles towards the determined peripheral zones from which they are to be collected. When all separable particles have reached the zones, the secondary vortices disappear as a result of their friction with the inner wall of the duct.

Figures 11-12

Heat exchangers are among the various types of translators to which the principles of the invention may be applied, and an example of this is provided by Figures 11-12. Heat exchanger 144 of Figures 11-12 is fabricated with a cylindrical shell 145 having upper and lower flanges 147 mounting upper and lower end caps 148,149, and includes in its upper portion a plenum 150.

Plenum 150 is a confined space defined by upper end cap 148, surrounding portions of shell 145 and transverse plenum wall 151. Below plenum 150 is secondary fluid chamber 152 extending down through shell 145 to transverse outlet chamber

wall 153. This same wall, along with the bottom portion of shell 145 and lower end cap 149, define the outlet chamber 154. Primary fluid enters plenum 150 through the cylindrical wall of shell 145 via primary fluid inlet 157 and passes into an array of congruent tubes 158 fixedly secured in leak proof relationship through transverse plenum wall 151.

Tubes 158 are congruent ducts similar to those used in the Figure 10 embodiment, have their upper ends flush with the upper surface of plenum wall 151 and extend downwardly in secondary fluid chamber 152 through first and second intermediate support plates 159,160. Passing through transverse outlet chamber wall 153 in leak proof relationship therewith, the tubes have their lower end flush with the bottom surface of that plate. The tubes are in open communication with outlet chamber 154 via which primary fluid may exit shell 145 through its cylindrical wall and primary fluid outlet 161.

By means of inlet 162, secondary fluid enters secondary fluid chamber 152, passes around and between tubes 158 in the spaces 163 which are between them, continues downstream through apertures 164,165 in the support plates and eventually is discharged from chamber 152 via secondary fluid outlet 166. Heat is exchanged between the primary and secondary fluids through the walls of the tubes in chamber 152.

<u>Figure 13</u>

The invention provides a variety of translators for use as separators, heat exchangers and in other applications, in which the amount of unused space between adjacent ducts may be reduced to a minimum. As will be readily found from an attempt to fabricate either the separator of Figure 10 or the heat exchanger of Figures 11-12 from non-congruent helical ducts such as are shown in Figures 9A-D, it is a particular

advantage of devices composed of ducts with congruent exteriors that they can be clustered in closely adjacent arrays.

In such arrays a plurality of matingly compatible congruent ducts can be stacked in a close-fitting array with their outer surfaces adjacent to each other in one, two or three directions, thus packing a large number of ducts into a comparatively small volume. Such arrays have comparatively low specific volume per unit of flow rate that can be processed through them, and can thus be used advantageously in systems with higher flow rates as compared to the non-congruent ducts. Thus, for example, in the case of a separator, one can economize on the amount of space required to provide a given amount of separation capacity.

By way of example, Figure 13 discloses a clustered array of congruent ducts 23 formed by displacement of a square figure, as illustrated by Figures 1-4. Note how the ducts can be clustered in contiguous fashion in both the vertical and horizontal directions. Ducts 69 of hexagonal cross-section, such as that disclosed in Figure 7N, can be assembled into arrays in which the ducts can be contiguous or closely spaced in three directions.

For the sake of simplicity, clusters comprising only a few ducts have been illustrated in the drawings. From these schematic diagrams, it may appear that the volume required to house the clustered ducts, and particularly the space occupied by their curvature, is very large in relation to their aggregate internal volume available for processing fluids. However, in industrial applications in which hundreds, thousands and even tens of thousands of such ducts may be congruently clustered, the extra space necessary to accommodate curvature at the sides of the cluster can be quite small in relation to the total duct internal volume.

Thus, it is possible to construct clustered embodiments of the invention in which the aggregate duct internal volume available for processing fluid closely approaches the total volume occupied by the ducts.

Figures 14-15

The invention also provides translators with clustered arrays of congruent ducts in which adjacent ducts have common walls formed of corrugated material. These are referred to as corrugated cluster translators. A few of many possible ways of constructing these are shown in Figures 14-20.

In general, a corrugated cluster translator has a cluster of plural rows and columns of elongated passageways. These define elongated, fluid flow paths for primary flows of streams of fluid which may be conducted through them, and have walls formed of webs of material of undulating cross-section, that undulate along the length of the flowpaths. The webs have ridges and valleys which, when viewed in plan view, extend at one or more angles that are skewed relative to major portions of the lengths of the flow paths, and are spaced apart from one another by distances which are sufficiently small in two or more directions to promote undulation of the primary flows in each of two or more directions transverse to the flow paths in the passageways. Among these are embodiments which may be fabricated from uni-directionally or bi-directionally corrugated sheets, as shown in Figures 14-15 and Figures 16-20, respectively.

A number of preferred embodiments of corrugated cluster translators are described below. They apply to translators fabricated from uni-directionally corrugated sheets, bi-directionally corrugated sheets, or both.

These embodiments provide ducts in which, if desired, a portion or at least a substantial plurality or preferably

all the passageways in the cluster, have one or more of the following characteristics or features:

- cross-sections in planes perpendicular to the general direction of flow that are of different or varying shapes; and/or
- centerlines substantially similar to a helical curve; and/or
- fluid flow paths with aspect ratios that increase and decrease along the length thereof in conjuction with said undulations; and/or
- lateral and vertical contiguity, so that the flow paths are juxtaposed in a way leaving substantially no unused space between them.

Other embodiments of the invention provide ducts which, if desired, have walls with one or more of the following characteristics or features:

- the walls of three or more passageways in a plurality of rows and/or columns of the cluster are different portions of the same or common webs; and/or
- the passageways have lower, side and upper walls each formed of webs of material of undulating cross-section; and/or
- the ridges of the webs of the side walls are non-co-planar with and at substantial angle of divergence relative to ridges of the webs of the lower and upper walls; and/or
- the webs have substantially rectilinear ridges and valleys; and/or
- the duct internal surfaces are each made of four assembled webs, each web being at least a portion of a corrugated plate, including a pair of vertical webs and a pair of horizontal webs, said pairs being engaged at the surfaces of one of said pairs and along the longitudinal edges of the other pair; and/or
- the passageway walls are stacks of, alternatively, (a) plates with undulating surfaces having ridges extending in

a first direction and (b) pluralities of spacers arranged between the plates with ridges extending in a second direction which is at an angle to the first direction, said spacers having margins whose projected marginal edge traces and surfaces conform to the undulating surfaces of the plates and and are in close-fitting engagement therewith; and/or

- the duct walls are composed of stacks of alternating corrugated plates and spacers, said plates having surface undulations with the shape of a first periodic curve, and the spacers having surface undulations with the shape of a second periodic curve similar but transverse to said first periodic curve; and/or
- the webs have an undulating cross-section substantially similar to a sine and/or cosine curves; and/or
- the duct walls are essentially composed of two sets of parts, all parts in each of said sets being identical.

Any of the above embodiments are useful in heat exchange apparatus and processes, and may also be used in separation apparatus and processes in which:

- at least a substantial plurality of the passageways in this cluster have inlets for receiving said fluid with dispersed particles and/or a source of dispersed particles, and
- the passageways subject these particles to centrifugal forces that concentrate the particles in one or more zones adjacent one or more of said walls.

In specific embodiments shown in Figures 14-15C, spacers 172 are cut from corrugated plate 173 having ridges 174 and valleys 175. By means of cuts extending from first edge 176 to second edge 177 of said plate, along first and second cutting lines 178,179, one can prepare a spacer whose surfaces conform to the corrugations of plate 173 and whose marginal edges 180,181 also undulate as shown by the

projections 183,184 of marginal edges 180,181 on viewing plane 182.

Spacers 172 formed in the above manner can be assembled with corrugated plates similar to plate 173 into an array of clustered, congruent generally helical ducts. This is illustrated by the exploded figure 15A which shows a plurality of corrugated plates 187-191, oriented with their surfaces generally horizontal, in a vertical array in which each plate is superimposed above and vertically spaced apart from the one below it. However, the spacing between the top two plates 187,188 has been exaggerated in order to show the spacers 172 which are arranged between them with their ridges and valleys extending generally vertically.

A number of spacers 172 are provided in laterally spaced relationship between each pair of corrugated plates 187-191. These maintain the vertical spacings between plates 187-191 and strengthen the structure against vertical loads. The marginal edges of the spacers are secured in close-fitting engagement or sealing relationship, preferably in abutment with, the adjoining plate surfaces, such as by or with the aid of brackets, clamps, other holding members, welding, gaskets, adhesives or other means.

In certain embodiments it may be convenient to fabricate stacking elements each formed of one of the plates 187-191 a full complement of spacers 172 secured to one of the surfaces of each plate. Assembling the components of the translator would simply involve piling up the stacking elements in a suitable container or chamber. Dismantling the translator for cleaning its components would then consist of opening the chamber and unpiling these elements. In certain circumstances, it may not be necessary to secure the horizontal members and spacers together. However fixedly

securing them together can be done if useful and generally is preferred.

When the plates 187-191 and spacers 172 are assembled in the foregoing manner in a housing 192 of rectangular cross-section, having top wall 193, side walls 194,195, bottom wall 196 and end walls 197,198, with appropriate openings in each end wall, such as opening 199 in wall 198, the plates and spacers form an array of ducts 200, four samples of which are indicated by arrows in the drawing. Plates 187-191 may be welded or otherwise secured by their longitudinal edges to the inner surfaces of the sides of housing 192. If the fluid to be treated is under pressure, the spacers and plates may be installed in a pressure resisting casing.

It will be appreciated that when the parts of this exploded view are assembled in the intended manner, the visible spacers 172 will be within the housing and will provide four additional ducts immediately above the twelve which are shown in the figure. These ducts also open through end wall 197 in a manner similar to that shown at end wall 198. In practice, it is possible and may be preferable to fabricate clusters having many more passageways than are shown in Figure 15A. Persons skilled in the art will readily combine this translator with appropriate fluid introduction and discharge arrangements suitable for a variety of applications, including particle separation, heat exchange and other applications mentioned above.

From the vantage point of an observer viewing the translator along a line perpendicular to the end wall 198, who is thus directly facing the duct entrances, ducts 200 appear as a plurality of juxtaposed squares with sides each having a length <u>a</u>. Seen from the opposite end, the duct outlets appear exactly the same.

The plate and spacer spacings may be varied if desired, but they are preferably equal. Thus, in this embodiment each channel defined by two consecutive plates 187-191 and two consecutive spacers 162 has a uniform transverse square cross-sections through a succession of planes perpendicular to the above-mentioned viewing line extending over a substantial portion if not all of the length of the channel. These cross-sections, with side a, stay congruent with themselves along the length of the duct.

The transverse cross-sections should not be confused with the flow cross-sections of the channel, the latter being described in the definition of "cross-section" below. Analysis of these cross-sections and of the flow centerlines derived therefrom provides interesting revelations. The flow cross-sections of this embodiment are four-sided figures of changing proportions and shape, of which the aspect ratio varies between a maximum and a minimum value, respectively higher and lower than unity. The walls of this preferred embodiment are characterized by ridges and valleys which, when viewed in plan view, extend at one or more angles that are skewed relative to major portions of the lengths of the flow path. Also, it is somewhat surprising to find that one can create congruent ducts having a generally helical or helical undulating flow paths with sheets of corrugated plates assembled in the above manner.

The nature of the undulations of these flow paths depends not only on the profiles of the plates 187-191 and spacers 162, but also on the relative positions or phase relationship of their respective ridges and valleys. For example, it is possible for the ridges and valleys of the plates 187-191 to lie respectively at like or different distances from the end wall 198, as compared to the distance between that end wall and the respective ridges and valleys of the spacers 162. However, these distances are preferably different, and in

such case it may be said that the undulating profiles of the plates 187-191 and spacers are substantially out-of-phase with one-another. This is illustrated by Figures 15B and 15C which represent the traces of the profiles of a preferred forms of plates and spacers on a common three-dimensional x,y,z axis coordinate system, these plates and spacers being similar to plates 187-191 and spacers 162 respectively except that they also include linear lead-in and exit portions.

Figure 15B shows a longitudinal, vertical trace of the preferred plate. For example, the surface of this plate, in longitudinal cross-section, except at its ends, may be a sine curve represented by the equation z = R.sin(2(PI)x/p) where R is the amplitude of the corrugations and 2(PI)p is their pitch, x and z being values on the x and z coordinates in the rectangular tri-dimensional coordinate system. To the left of the origin of the x-coordinate axis there is preferably a quarter wave end as shown to cause the fluid to enter the translator parallel to the x-axis. A similar provision is preferably made at the other ends of the plates, to insure that the outlet of the fluid is parallel to the x-axis.

Figure 15C shows a longitudinal, horizontal trace of the preferred vertical spacers. For the reasons given above, the shape of this cross-section, except at its ends, is a cosine curve having the equation y = R.cos(2(PI)x/p) where R is the amplitude of the corrugations and 2(PI)p is their pitch; both are the same as for the plates. To the left of the origin of the coordinate axis, there is preferably a rectilinear end that causes fluid to enter the translator parallel to the x-axis. A similar provision is preferably made at the other ends of the spacers, to insure that the outlet of the fluid is parallel to the x-axis. The horizontal distance between the spacers 79 is uniformly equal to a. When the spacer margins conform to the curve of Figure 15C, it should be

apparent from this description and from geometric principles that the traces of the plates and spacers are preferably out of phase with one another by about one quarter of a wave.

Modifying the size of, and/or the ratios between any of the parameters $\underline{R}$, $\underline{p}$, and $\underline{a}$ can be used to alter the character of the flow path. Also, one can add a constant lead or lag to the angle which defines the difference in phase between the plate and spacer ridges. For instance, considering the fact that a cosine has been used in the definition of the spacer parts, if one adds 90 degrees to that angle, one will not obtain a helical coil with a more or less constant cross-sectional area, but rather a curved convergent / divergent channel having the shape of a sine curve. By adding an angle smaller than 90 degrees, one will obtain an intermediate shape of channel, which has specific advantages since it incorporates a distorted convergent / divergent flow path. Other specific advantages can be obtained for example by replacing the constant $\underline{a}$ by a negative exponential function wherein the exponent is proportional to $\underline{x}$; this change gives channels with a decreasing cross-section. One may also use periodic functions other than sine or cosine, thus changing the helical curve into a more complicated periodic turning curve (called hereafter a "pseudo-helix") which may have specific advantages, without losing the basic advantages of the exemplified translator. One may also design the translator on the basis of an oblique instead of rectangular x-y-z coordinates system.

The translator thus described has several unique advantages, among which its compactness, since there is no void space between the flow channels, which with their walls can substantially fully occupy the total volume available. Another unique advantage of this translator is its extreme simplicity. Indeed, it can be formed entirely of only two different kinds of parts, a set of spacers 172 and a set of

plates 187-191. While there may possibly be variations among the parts in a set, the parts within the respective sets are identical in this preferred embodiment. Moreover, the spacers may be formed of the same raw material as the plates. Moreover, a unique advantage of this general type of translator is design flexibility which facilitates varying the configuration of the passageways and resultant flow paths.

Figures 16-20

The embodiments of Figures 16-20 exemplify corrugated cluster translators with passageways that may have one or more of the following characteristics:

- walls formed of webs having channels with non-rectilinear ridges and valleys extending in a given direction in said webs, said channels having undulations along their length, extending in another direction in said webs which is transverse to said given direction; and/or
- undulating cross-sections that are characterized by non-rectilinear ridges and valleys having an undulating shape along their length and, when viewed in plan view, have ridges and valleys which extend at one or more angles that are skewed relative to major portions of the lengths of the flow paths; and/or
- confronting sets of walls including lower and upper walls located one above another, each formed of webs of material of bi-directionally undulating cross-section, the ridges of the lower walls being adjacent or contiguous with and tangent to the valleys of the upper wall; and/or
- being composed of a set of similar or identical bi-directionally corrugated plates forming an array of clustered congruent ducts.

Figures 16-20 address fabrication of corrugated cluster translators with fluid flow path enclosing walls formed of bi-directionally undulating webs with non-rectilinear ridges

and valleys having an undulating shape along their length. As shown by the figures, these obviate the need for spacers and provide passageways with a variety of shapes in their transverse cross-sections, such as the substantially square cross-section of Figures 16-17, the hexagonal cross-section of Figure 18 and the rounded or circular cross-sections of Figures 19-20.

A bi-directionally corrugated plate 204 is illustrated in Figure 16. This elongated plate has first and second ends 205,206 and sides 207,208. The upper and lower surfaces of the sheet include alternating upward- and downward-facing open channels 209 having undulation in a first direction, comprising ridges and valleys extending across the width of the sheet, upon which are superimposed ridges and valleys extending generally longitudinally.

Thus, the plates have a first system of ridges and valleys superimposed on a second such system which is skewed relative to the first. Such a doubly corrugated plate appears more complicated to fabricate, but can be mass-produced cheaply by various methods, such as by pressing a sheet between matrices.

The trace of the end of the second system of undulations in plate 204 is identified by reference numeral 211 in the Figure 16 perspective view and in the Figure 17 end view. In the latter view, plate 204 is stacked up with one or more additional and similar plates 210. Note that the end profile 211 typical of plates 204 and 210 includes a repeating system of crests 216 and roots 217 joined by flanks 214;215. Also, the flanks 214,215 converge slightly in the downward direction so that they may rest on a corresponding crest of the plate below.

Similar principles can be applied to bi-directionally corrugated plates similar to plate 204, in which the channels 209 are modified to give them an end profile conformable to a hexagon, such as in sheets 220, 221 and 222 of Figure 18. Taking sheet 222 as an example, these sheets have channels with a system of flanks 223,224 which are at angles of 60° to the crests 225 and roots 226 which they connect. When a number of these sheets are stacked or preferably secured together in contiguous stacks, they form a plurality of hexagonal ducts 227.

According to another alternative embodiment shown in Figures 19-20, the bi-directionally corrugated plates may have channels which undulate both longitudinally and laterally in waves resembling a repeating cosine curve. For example, one may stack together a plurality of cosine wave plates 229-232 in a system of corrugations in which the crests 233 and roots 234 of the plate end traces are of circular cross-section, and in which there is root-to-crest contact between adjacent plates throughout their length.

The walls of the resultant ducts, viewed in transverse cross-section, have portions 235,236 which are generally circular, and other portions 237,238 which are convergent. These ducts therefore have a generating figure similar to a circle but having two small diametrically facing corners resembling the crease between the lips of the human mouth. As shown by Figure 20, the cross-section may be made fully rounded by providing fillets 239 which extend longitudinally with the adjoining crests and roots along the length of the ducts.

The basic ducts and corrugated plate elements in the embodiments of Figures 14-20 have been described as horizontal and the spacer elements as vertical for easier understanding. However, in all the embodiments of the invention having components in the form of ducts or of basic

corrugated plates with or without spacer parts, the separator can be put in any position, and not only in the position resulting from the description given in this specification.

Figure 21

This embodiment relates to translators and related processes involving ducts and/or processing with one or more of the following features:

- at least one bent portion the centerline of which has a curvature and/or a torsion increasing in the direction of the flow, and/or
- a progressively modified cross-sectional shape or area, and/or
- a general helicoidal and/or pseudo-helicoidal and/or helico-spiral and/or pseudo-helico-spiral and/or spiral and/or pseudo-spiral shape; and/or
- increasing the curvature of at least a portion of the streamlines of the flow path as the flow progresses; and/or
- increasing the torsion of at least a portion of the streamlines of the flow path as the flow progresses; and/or
- modifying the shape and/or reducing the size of the cross section of the flow path as the flow progresses; and/or
- a flow path for the primary streamlines in the confined stream which comprises:
  - (A) a first portion in which both the curvature and the torsion of said streamlines are small as compared with the inverse of the hydraulic radius of the corresponding cross-section of the flow path;
  - (B) a second portion in which the turning of the streamlines does not exceed one turn and wherein both their curvature and their torsion are substantially similar to the inverse of the hydraulic radius of the corresponding cross-section of the flow path; and

(C) a third portion wherein the length of the streamlines is equal to a large number of times the hydraulic radius of the cross-section of the streamlines at the inlet of said third portion and wherein both the curvature and the torsion of the streamlines are small as compared with the inverse of the corresponding cross-section of the flow-path.

By way of example, Figure 21 shows the plane projection of an embodiment of the translator according to the invention, which may for example be a separator, wherein a very strong secondary flow is generated in duct 242. The duct has several sections 247-249 delineated by reference lines 243-246. To control eddy formation and head losses, each section is formed by congruent displacement of circumference, which is preferably a circle, along a generating line.

Flow shaping section 247 of the separator has an inner surface generated by the substantially congruent displacement of a circumference along an inlet generating curve. The curvature and the torsion of said curve are small as compared with the inverse of the radius of the corresponding cross-section of the flow path.

The second portion 248, which connects smoothly with the first portion 247, has an inner surface generated by the substantially congruent displacement of said circumference along an helical generating curve of which the curvature and the torsion are substantially similar in magnitude, say with a factor of about 0.7 to 1, to the inverse of the hydraulic radius of the corresponding cross-section of the flow path. Due to this similarity or small value of said factor, the stream undergoes in section 248 a strong separation from a substantial portion of the wall and thus fills only very partially the local cross-section of the duct.

After having followed about one half turn to one turn of said helical pathway, the stream enters section 249 of the separator, which is generated in a way very similar to the generation of section 247, except that section 249 is much longer and that it has a major helical portion, wherein the incoming stream enters at a substantial angle (say about 40 to 50 degrees) with the center line of the duct. Due to the shape of section 249, there is no more flow separation in this section, and due to said inlet angle of the stream, the streamlines in section 249 have a peripheral transverse velocity, i.e. a velocity of the secondary flow, which is similar in magnitude to the velocity of the primary flow. Such a strong secondary flow persists along a very substantial length of the duct, say at least about 50 to 100 times the hydraulic diameter of said section 249. It creates a very intense centrifugation field which causes the separation of the dispersed particles which can be separated from the stream. Said separated particles may then be collected as in other centrifugal separators.

For information on parameters which govern flow separation in bends, one may refer to the publication of NAOHIRO SHIRAGAMI and ICHIRO INOUE in "Pressure Losses in Rectangular Bends," Chapter 26, pages 870 to 895, the contents of which are hereby incorporated by reference. Regarding generation of strong swirls by quasi-coil pipes, one may refer to the following publications:

-HIDESATO ITO, "Flow in Curved Pipes", JSME International Journal, 1987, Vol. 30, No. 262, pages 543-552 (see paragraph 3.3 Bend Interactions and corresponding references).

-YUKIMARU SHIMIZU et al, "Flow Patterns and Hydraulic Losses in Quasi-Coil Pipes (The effects of configuration of bend cross-section, curvature ratio and bend angle)", Bulletin of JSME, Vol. 28, No. 241, July 1985, pages 1379-1385.

Figure 22

This figure exemplifies apparatus and processes in which:

(A) a confined stream includes gas carrying a condensable vapor and undergoes in a first portion of its path an expansion by acceleration causing at least a portion of said vapor to condense in the form of small liquid particles dispersed in the thus accelerated gaseous stream and having a size sufficient for permitting their separation by the process;

(B) the confined stream thus obtained then enters a second portion of its path where it undergoes separation of a substantial part of the condensed particles with or without further expansion by acceleration and/or at least partial recompression by deceleration; and

(C) the confined stream thus obtained undergoes in a third portion of its path a recompression by deceleration.

Figure 22 shows a plane projection of a particular embodiment of the foregoing wherein the gaseous mixture to be treated includes a substantial quantity of a condensable vapor component. In this embodiment, the duct 253 is at least conceptually divided into several portions by reference lines 254-257, and includes expansion section 258 followed by separator section 259 and then recompression section 260.

The expansion section 258 may include for instance a convergent axisymmetric nozzle of circular cross-section, wherein the incoming gas expands, thus transforming part of its pressure energy into kinetic energy not exceeding an amount corresponding to the velocity of sound. Known methods exist for calculating the actual thermodynamic evolution of the expanding gaseous mixture along section 258 as a function of its profile, on the basis of a large number of test results reported in the literature. In particular this profile can be designed in such a way to generate condensate in the form of droplets with a diameter of about one

micrometer when the flow reaches a velocity in the vicinity of the velocity of sound.

The outlet of section 258 connects with the inlet of the separating section 259, which is generated by the substantially congruent displacement of a circumference along an helix of which the length is equal to about one to two turns, and of which the p/R ratio is in the range of about 4 to 7. The ratio R/r between the radius of the helix and the radius of the circumference must be sufficient (say at least 3 to 4) in order to prevent flow separation of the stream in section 259. It may be advantageous that the radius of the generating circumference of section 259 slightly increases in the direction of flow, in order to extend the expansion of the stream until the Mach number reaches about 1.2, thus increasing the quantity of condensate and the size of the condensate droplets. Nearly complete separation of these droplets occurs in the first part of section 259, which includes collection means (not shown) for said droplets. After said separation, the stream may undergo a shock wave which reduces the flow velocity to a subsonic value, at which the flowing stream leaves section 259. In recompression section 260, for instance a divergent axisymmetric nozzle of circular cross-section, the kinetic energy of the flowing stream is transformed into pressure energy.

In the foregoing device, heat produced by condensation of a portion of the vapor component of the initial gaseous mixture is transferred to the high velocity gas before its recompression. Thus, the gas leaving the device not only has reduced relative and absolute humidity, but also a temperature substantially exceeding the temperature of the incoming gas mixture. The energy for this heat pumping effect in the device is provided by the pressure loss incurred by the gas mixture across the device. Thanks to the very high isentropic efficiency of the expansion and

recompression of the gas in sections 258 and 260 of the device (both said efficiencies being about 98%), and to the reduced losses occurring in section 259, the total pressure drop of the gas to be treated in the device does not exceed about 6 to 10% of its absolute stagnation pressure at the inlet of the device. Said efficiency is highest when the inlet gas is saturated with that vapor of which a portion is to be separated. The specific energy consumption of such a heat pumping device per kg of separated vapor in liquid form may be lower that 500 kJ.

Concerning separating nozzles for extracting vapor in liquid form from gas/vapor mixtures, one may refer to
-European Patent Specification No. 0 162 509, MALDAGUE, "Process and Apparatus for Extracting Liquids From Aggregate and From Gas/Vapor Mixtures."

Concerning existing known methods for calculating the actual thermodynamic evolution of the expanding gaseous mixture in a converging / diverging nozzle as a function of its profile, relevant software and services can be obtained for instance from the Royal Military Academy of Belgium, Chair of Applied Mechanics, Avenue de la Renaissance 30, B-1040, Brussels, Belgium.

Concerning the isentropic efficiency of expansion and of recompression in a converging/diverging device, one may refer to Perry, Chemical Engineers' Handbook, 1950 Edition, last paragraph of page 406, "Venturi Meters," stating that the pressure loss is 10 to 20% of the reading, which corresponds in a well designed deLaval nozzle to a global isentropic efficiency of 96% when the velocity nears the velocity of sound in the throat of the nozzle.

<u>Figure 23</u>

The invention can be applied to perform heat and mass transfer operations between a gas and a liquid in a very compact way, with or without chemical reaction. Such operations are usually performed in scrubbers equipped with packings for dispersing liquid which drips through the gas. When one employs a separator according to the invention and atomizes into a gas a liquid for exchanging heat and/or materials with said gas, the relatively large droplets produced by atomization can be fractionated in a first portion of a separator into smaller droplets having a very large contact area, and can then be separated by centrifugation in a second portion of said separator.

This aspect of the invention includes apparatus and process embodiments which can if desired involve one or more of the features of:

- atomizing droplets of a liquid in a fluid for exchanging heat and/or mass with said fluid; and/or
- fractionating the atomized droplets to droplets of a smaller size in a portion of a flow path where centrifugation occurs; and/or
- causing atomized droplets to react physically and/or chemically with a flowing fluid during their centrifugation; and/or
- causing physical and/or chemical reaction between fractionated droplets and a fluid stream to take place substantially in a portion of a flow path where centrifugation but little separation of the fractionated droplets are caused to occur, said separation being caused to occur in a subsequent portion of the flow path.

Figure 23 shows by way of example the plane projection of an embodiment of the invention wherein heat and/or mass exchanges, with or without accompanying chemical reactions, may be performed between a liquid and a gaseous mixture to be treated therewith. When in the past this type of operation

has been performed in scrubbers, packings have been used to disperse downwardly dripping liquid into an ascending flow of gas. In such scrubbers, the velocity of the ascending gas has been limited to low values in order to prevent the entrainment of small liquid droplets by the gas, and also because the conditions in which diffusion takes place between the liquid and gaseous phases are subject to the limitation of the driving force which is gravity.

Contrarywise, an advantage of the invention is that it can be practiced with ducts of relatively large cross-section and at relatively high flow velocities without undue increase in backpressure. Quick transit time provides the opportunity of controlling or inhibiting unwanted chemical reactions in the fluid, by providing for rapid and effective contacting and de-contacting of reactive materials.

Also, this embodiment of the invention allows miniaturization of the process, because not only much smaller droplets (in the range of one to several micrometers) can be made and used, thus considerably increasing the surface to volume ratio of the liquid, but also because the conditions in which diffusion takes place between the liquid and gaseous phases considerably enhance the rate of diffusion. Indeed, the role played by gravity in conventional scrubbers is replaced in the invention by a primary acceleration field, the magnitude of which may be several hundred times the magnitude of gravity. Although the droplets used by the invention may be as small as one micrometer or less, the separating capabilities of separators according to the invention makes it possible to thoroughly and rapidly separate such droplets from the gas phase after they have reacted with it.

The invention also can control a major problem with the fluid effluents of scrubbers used to treat stack gases of steam boilers, waste chemical incinerators and the like.

Such scrubbers dissolve the environmentally undesirable components of such stack gases in a cascade of liquid which normally includes chemical adsorbents. The upward flow of stack gas through the liquid entrains tiny droplets of liquid, and is then processed through conventional aerodynamic separators, which are unable to separate sub-micron aerosols, i.e. those droplets which are about 1 micron or less in diameter and remain in the off-gases of the scrubber if they are discharged to the atrmosphere. The chemical contents of these droplets may exceed the limits defined by environmental regulations. Initial attempts to remove these droplets with prior art helical coil separators proved unsuccessful until the small droplet-containing scrubber off-gases were seeded with larger droplets of liquid. This technique, or alternatively the replacement of the existing aerodynamic aerosol separators by less efficient ones, enables helical ducts, congruent or otherwise, to provide highly efficient separation of small particles with minimal backpressure and at high flow rates per unit of specific volume. Thus, the invention obviates the need for huge filter houses or other economically punishing alternatives.

The above embodiments are exemplified by Figure 23, in which mini-scrubber processing duct 264 appears between reference lines 263 and 271. One may for example use a duct of at least 0.5 revolutions, preferably at least one revolution, with a preferred range of about 0.5 to 2 revolutions; but if further contact time is required, the number of revolutions necessary may considerably exceed the foregoing.

At 263, a gaseous mixture to be treated enters upstream portion 269 of the duct, its inner surface having been generated by substantially congruent displacement of a circumference along an helical curve. At the beginning of section 269, a reacting liquid is delivered via pipe 265 to

atomizer 266 and is atomized to droplets 268 with sizes of at least about 30 microns or more that are dispersed in the entering gas. Thse droplets are projected against the inner wall of portion 269 of the duct, from which they rebound while splitting into droplets of smaller size, which in turn rebound and split again and again until their sizes are reduced to a few microns or less. A substantial portion of said smaller droplets are too small to be separated in the first part of section 269 of duct, where the velocity of the gas is kept below about 10 m/sec. Nevertheless, along the full length of portion 269, the droplets are subject to a rotating acceleration field of several hundred times the acceleration of gravity g, thus enhancing the heat and/or mass transfer, including chemical reactions, between the droplets and the flowing gas. The length of portion 269 of the duct is designed such that the residence time of said droplets within the flowing gas is adequate for the intended transfers to occur completely. In the second part of section 269, in which the gas / droplets mixture continues to flow downstream, the radius of the generating circumference is progressively reduced by a factor in the range of about 1.3 to 1.6, without changing substantially the parameters of the generating helix. The velocity of the gas stream flowing in the duct is thereby increased by a factor of about 1.7 to 2.3. The gas / droplets mixture then enters duct downstream portion 270 in which its increased velocity is maintained. Due to the higher velocity of the gas/droplets mixture in portion 170 of the duct, the major portion of the droplets will be separated by the combined action of the increased primary flow acceleration field and of coalescence, as explained for example in connection with Figure 10. The gas then leaves duct portion 270 at 271 while travelling parallel to the axis of the generating helix.

Congruent and Non-Congruent Separators

The invention includes a method for improving the collection efficiency of both congruent and non-congruent helical duct separators that have a threshold particle size, i.e. the size of the smallest particles which the separator can separate with nearly complete efficiency, e.g. at least 99%, from a dispersion of substantially uniformly sized particles.

A first embodiment of this method includes the following steps and can employ either a non-congruent one illustrated by Figures 9A-9D or a congruent helical duct illustrated in any of the remaining figures, but apparatus similar to that in Figure 23 is used in the following illustration.

In a first step, fluid containing dispersed particles and/or a source of dispersed particles, including substantial quantities of particles above and below said threshold, is conducted in turbulent flow through section 263 in the first portion 269 of the helical duct separator 264. Immediately after the inlet of section 269 at 263, an auxiliary liquid delivered by pipe 265 is atomized by atomizer 266 in the form of droplets 268 which are dispersed in the entering fluid. The auxiliary liquid atomized by the atomizer may be any liquid which is coalescible with the smaller particles to be separated. Preferably, when said particles are liquid, the auxiliary liquid may be recycled, previously separated liquid. The atomized droplets are at least about 30 microns or more in size. They are projected against the inner wall of portion 269 of duct 264 where they rebound while splitting into still smaller droplets, which rebound and split again and again until their sizes are reduced to a few microns or less.

A substantial portion of these smaller droplets are too small to be separated in section 269 of duct 264, where the velocity of the fluid is controlled and kept below a ceiling value, e.g. about 10 m/sec. Portion 269 of duct 264 is

designed such that at its outlet to transition portion 272 the ratio of numbers of particles above and below the threshold size can be controlled by varying the velocity of the fluid within the aforesaid limit. At lower velocities of the fluid, the ratio of larger particles to smaller ones increases, and at higher velocities, said ratio decreases, due to corresponding variations in the intensity of the centrifugal acceleration field.

In transition portion 272, the internal cross-section of the fluid passageway is progressively reduced by reducing its transverse dimensions by a factor in the range of about 1.3 to 1.6, without substantially changing the parameters of the generating helix. The velocity of the fluid stream flowing in the duct is thereby increased by a factor of about 1.7 to 2.3. The fluid mixture containing said particles, having reached said increased velocity, then enters portion 273 of the duct where its newly established higher velocity is maintained.

This higher velocity of the fluid - particles mixture, is not only maintained in portion 273 of the duct during centrifugation of the mixture, but also during redirecting of the velocity of the fluid in straightening portion 270 so that it is parallel to the axis of the generating helix for the duct, until the fluid leaves portion 270 at 271. Due to the increased velocity, the centrifugal acceleration field increases considerably and causes particles having sizes above the threshold to move towards the inner wall of the duct and thus separate from the fluid. While moving toward the wall, these larger particles exert a sweeping action on particles having sizes below the threshold and coalesce with the latter.

Coalescence is explained in connection with the description of Figure 10 and in the definition of coalescence below. By

coalescence the smaller particles are separated along with the larger particles with which they have coalesced. In such a process, a major portion of the particles below the threshold size can be separated in a single pass through the separator.

In the aforesaid embodiment, a substantial quantity of relatively larger particles having a size above said threshold are introduced into or generated in the stream, during or prior to the flowing of the stream through the duct and prior to completion of particle separation. However, in another embodiment, the feed to the helical separator can be dispersed particle-containing fluid effluent from an upstream separator discharging the requisite, or higher, proportions of particles of the required sizes. If said proportions are the ones needed, it is not necessary to use parts 269, 265, 266, and 272 of the separator 264.

Another embodiment of the method according to the invention includes providing a liquid film on at least a substantial part of the inner surface of a helical duct separator, whether or not the separator is congruent. This method also permits the separation of dispersed particles and/or a dispersed source of particles, including substantial quantities of particles below said threshold.

A layer of liquid is provided upon a wall in the helical duct, in or upstream of the separation zone, and is caused to flow downstream in the duct in the same general direction as the fluid stream. A substantial portion of the particles below the threshold are brought into contact with and caused to coalesce with the liquid layer, and such particles are then separated from the stream with the liquid layer. In such a process a substantially increased proportion of the particles below the threshold size can be separated, as compared to operation without the liquid layer.

The phenomenon of separation of the smaller particles is due to the combined action of turbulence and centrifugal force, which brings a substantial portion of said smaller particles, somewhere along their very sinuous travel, at such close distances of the liquid layer, that they coalesce with that layer which thus absorbs and separates them from the stream.

There are a number of known methods which can be used to form such a liquid layer. One of them is to pulverize a liquid very coarsely in a stream of incoming fluid at or after the inlet of the separator. Another method is to atomize a liquid in the manner described above. Indeed, in any of the latter methods, a layer of liquid is formed on the wall of the helical duct and propelled downstream along the wall by surface contact with the stream of flowing fluid.

Examples

The following are purely illustrative and appropriate but not limiting sizes for the separating section of a congruent duct separator, when employed with gaseous fluids similar to air at about atmospheric stagnation pressure, it being understood that very different sets of parameters may be used:

- for separating dispersed liquid coalescible aerosols present in the fluid at rest or at velocities in the range of about 15 to 30 m/sec, the radius r of the circumference used as a generating figure for the duct separator is about 15 mm, the radius R of the generating helix is in the range of about 45 to 60 mm, the pitch factor p is about equal to R, the number of turns of the helix is about 5, the corresponding length of the separator section is between about 1.5 and 2.0 m and its developed length is between about 2.0 and 3.0 m.

- for separating liquid aerosols dispersed in high velocity (e.g. 300 to 400 m/sec) gaseous fluid as a result of

condensation within an expansion section of a duct, the radius r of the generating circumference is about 5 mm, the radius R of the generating helix is at least 10 to 15 mm, the pitch factor p = 4.0 R, the number of turns in the helix is about 1 to 2, the corresponding length of the separator section of the duct is between about 0.25 and 0.75 m and its developed length being is about the same.

- for solid non-coalescible aerosols the separators may be one typically used for liquid coalescible aerosols or may have an upstream flow shaping subsection as illustrated by Figure 21; in the latter case, the flow shaping subsection has a generating circumference with a radius r of about 15 mm, a generating helix with a radius R of about 20 to 25 mm, a pitch factor p about equal to R, and about 0.5 to 1.0 turns in the helix, the corresponding length of this subsection being about 50 and 150 mm and its developed length between about 70 and 200 mm; the flow shaping section is followed by a longer subsection with the same radius r, but with a different constant value of R and of p, the transition from the former to the latter regular helices being made by a connecting section having variable helix radius and pitch; the latter regular helix would have a radius R of about 50 mm, a pitch factor p of at least about 5xR, and less than about 1.5 turns, both the corresponding length and developed length of the latter subsection being about 1.5 to 2.5 m.

- to create dispersed liquid aerosols of a size not exceeding a few microns for causing physical and/or chemical interaction between such aerosols and the carrying gas within a chamber, the apparatus of the first foregoing example, i.e. the one corresponding to a separator section for separating pre-existing liquid aerosols, can be used as explained in the foregoing description of the device as portion 273 of the duct, with

the characteristics of portions 269 and 272 deriving from those of portion 273 as explained in the foregoing description (i.e. with transverse dimensional parameters multiplied by a factor of 1.3 to 1.6, to reduce the velocities by about one half).

Unless it is specifically intended to create flow separation within the duct according to the invention, as exemplified by the embodiment illustrated by Figure 21, flow separation should be prevented within the duct to attain high levels of performance. To prevent flow separation the ratio R/r of the radius of curvature of the generating curve to the hydraulic radius of the generating closed figure should exceed a minimum between about 2.5 and 4.0 throughout the duct, depending on the Reynolds number of the flowing stream.

For best results in separating aerosols of a given size from a fluid:

- said size should be at least equal to the threshold size of any non-coalescible particles that can be separated from the fluid by the primary centrifugal acceleration field, or
- if said size is smaller than said threshold size, the particles should be coalescible (either inherently or by being wet by a coalescible liquid) and should be contacted in the separator by particles with which they are coalescible and which have a size larger than said threshold size.

A laboratory unit comprising a substantially congruent helical duct was constructed according to the general scheme disclosed in Figures 8A-8D, with modifications shown in Figures 24A and 24B. The design embodies the concept of a substantially congruent duct having circumferences as cross-sections perpendicular to the axis of the generating helix and one or more zones generated by such cross-sections which

are non-axisymmetric at intervals along its length, and preferably including at least one such zone within the first turn of the generating helix. The planar closed figure could be described as a circle of which the shape (and corresponding area) was progressively changed, during its congruent displacement, first into an ellipse, then back into the initial circle, and so forth, every 90 degrees of its helical translation.

As shown by Figure 24A, which has the same orientation as Figure 8B, these transitions took place at centers 281-285, resulting in shapes 276-280. Transverse dimensions of the duct were as follows:

- the diameter of circles 276, 278, 280, and additional circles at the same angular intervals along the generating helix.. 31 mm
- axes of the ellipses 277 and 279, and additional ellipses at the same angular intervals along the generating helix:
  - major axis.................................... 35 mm
  - minor axis.................................... 26 mm

The dimensions (rounded off in mm) of the reference segments AB shown in Figure 24B (which for this duct is the equivalent of Figure 8D) varied progressively from 31 mm to 26 mm to 22 mm to 26 mm to 31 mm for the cross sections with centers 281-285, respectively. The orthogonal segments CD varied from 22 mm through 26 mm to 31 mm and back through 26 mm to 22 mm for cross-sections with respective the centers 281-285. These cross-sections are alternatively elliptical and circular.

The wall of the substantially congruent helical duct was fabricated of commercial plastic garden hose having an inner diameter of 25 mm and an outer diameter of 31 mm, secured around a straight steel pipe having an outer diameter of 76 mm with a generating helix radius of 59 mm and an helix angle of 45 degrees. The hose was held in place by steel collars secured to the pipe at intervals of 45 degrees along the

helix path, said collars having alternating elliptical and circular shapes coinciding with the planes of duct cross-sections of Figure 24B. The duct developed length was 2,620 mm and its axial length was 1,855 mm. Throughout its length the duct was thoroughly insulated and provided with heat tracing to maintain adiabatic conditions within, and observation ports were provided at various points.

Tests made on non-congruent helical models of circular cross-section have produced significant swirls which do not appear to have contributed in a major way to separation of the smallest particles in the submicron range. However, tests made on the substantially congruent helical duct described here above have shown that no substantial swirl of the flow was generated, with ensuing reduced headloss. A large number of tests were made at temperatures between 20 and 60 degrees C, using the aforementioned duct as a liquid aerosol separator. Excellent separating efficiencies for very small particles have been realized, as illustrated by the histogram of Figure 25.

The efficiency curve represented by Figure 25 was produced as follows. A flow of air saturated with water vapor and containing water droplets was caused to flow through the above described duct at a velocity of 16 m/s. Transparent portions of the duct at its upstream and downstream ends permitted observation of the stream and its contents. Pressure drop measurements showed that at velocities in the vicinity of 16 m/s the head loss across the separator was between about 0.005 and 0.01 times the absolute stagnation pressure of the gas at the inlet of the separator.

Observation of the stream with an HeNe laser beam under similar azimuth and elevation angles at the inlet and outlet sections respectively showed very bright reflections of dispersed droplets in the inlet section and no visually

observable droplets in the outlet section. Observations with a Malvern particle sizer, which measures droplet size based on Fraunhofer diffraction, and has a lower detection limit of 1.2 microns, indicated that all droplets at the inlet were in the range of 0 to about 10 microns, while no measurable droplets could be detected at the outlet. An HC Polytech particle sizer, a well known and commercially available unit capable of measuring particle size and abundance in the range of 0.3 to 22 microns (and within other ranges) was then used to take particle counts and size distributions at the separator inlet and outlet.

A histogram of droplet distribution at the inlet showed detection of 49,768 particles per 60 seconds throughout the range of about 0.3 to about 10 microns, with most of the particles being less than 1 micron and the largest abundance of particles having a particle size of about 0.5 microns. A histogram of the particles counted at the outlet indicated detection of 1120 particles per 60 seconds, with all particles above about 0.8 microns being completely removed and with the peak particle concentration being at about .4 microns.

Figure 25 shows the unoptimized separation efficiency of the operation for all particle sizes introduced into the unit. As shown in the graph, the separation efficiency is 75% or better throughout the range from .3 to about .6 microns, and essentially 100% from .6 microns on up through the upper limit of particle size detected in the feed. This as yet unoptimized system represents the first known achievement of these levels of efficiency in a duct having the very low head loss characteristics and clustering capability of the present invention.

The use of coalescence to separate very small particles from fluids was explored in a series of tests with the laboratory

unit. A primary separator was connected upstream of, and in series with, the laboratory unit. The primary separator was supplied with a gas/particle mixture and extracted from that mixture all particles having a size exceeding one micron, thus leaving particles having sizes of one micron and less to be separated in the laboratory unit. It was found that these particles were below the threshold level for the laboratory unit. The separation efficiency of the latter micron and submicron particles was near zero. When the primary separator was by-passed, the laboratory unit was able to reduce the number of micron and submicron particles in the gas/particle mixture by a factor of 30, and all particles of 0.5 micron and above were separated. Only a much reduced number of particles below 0.5 microns was left in the gas leaving the separator.

Industrial Utilization

The invention can be embodied in a variety of ways, some examples following on the basis of constructions using (a) flexible hose, (b) rigid extruded congruent tube or (c) corrugated plates.

A separator unit for coalescible liquid particles having sizes including 0.3 to 0.9 microns can be made as follows for industrial demonstration purposes. The unit comprises 400 flexible ducts, each being a portion of commercial garden hose having an ID of 25 mm, OD of 31 mm and a length of 3 m. The unit also comprises 41 square plates of rigid plastic or steel material of a few millimeters thickness, the side of the square being 1 m. All these plates are drilled with holes of which the centers are located on a triangular array of 40 x 40 x 40 mm with 37 mm bore holes perpendicular to the plate. If the plates are thick, the backs of the plates surrounding the holes are counter-bored with a large bore to reduce the length of the sidewalls of the original holes as far as practicable without enlarging their diameter. There

are 20 rows of holes, each row containing 20 holes. The total array thus includes 20 x 20 = 400 holes, one for each hose. The 41 drilled plates are placed in parallel equidistant locations of which the first and the last ones are distant by 3 m. While the plates have all their borderlines and their holes aligned, the 400 hoses are introduced each one in a series of rectilinearly aligned holes. After that introduction, all plates but the first, the ninth, the seventeenth, the twenty-fifth, the thirty-third and the forty-first are displaced congruently to the first plate in such a way that each series of holes is no more rectilinearly aligned, but is aligned along an helix having a radius of 67.5 mm and a pitch of 424 mm. This displacement will reduce the distances of the corresponding faces of the plates from 75 mm to 53 mm. All hoses will completely fill the holes in the plates and will take the shape of congruent helices of 67.5 mm radius and 424 mm pitch. The plates thus disposed may then be secured inside an outer casing having an inlet plenum and an outlet plenum for the gas loaded with liquid aerosols to be separated. Such a unit is very cheap to construct, and is appropriate for conditions which do not result in severe temperature or corrosion damage to the helically shaped hoses during the period of time required for the demonstration. An alternative demonstration unit may be built, having the foregoing method of construction, but based on the parameters of the above-described laboratory unit.

For industrial separators requiring conformity to appropriate materials specifications, a preferred type of construction is similar to that used for shell and tube heat exchangers. However, rigid, congruent helical extruded tubes having the required shape and arrayed as in the above demonstration unit are substituted for the conventional rectilinear tubes. A simple way of fabricating such congruently helical tubes in polypropylene for instance, is to extend the core of the

extruder by an amount of length which is a fraction of the pitch of the helix (in the range of 0.125 to 0.25), said extension having an external shape identical to the inner shape specified for the duct. This affords an opportunity to use a duct made of an annular part formed from raw material to its final shape in one main fabrication operation. Congruent helical ducts can thus be fabricated by simple modifications of existing methods at competitive prices similar to the prices of similar straight ducts. Additional lengths may be provided on each duct, constituting inlet and outlet portions permitting a gaseous stream to enter and to leave the duct with a velocity parallel to the axis of all helices.

Definitions

The following definitions apply to the present disclosure of the invention and to the claims which follow:

"Aspect ratio" is the ratio between the reference segment and the orthogonal segment of a cross-section or of its borderline.

"Bend" means a curve having a finite curvature at any point along a substantial portion of its length and/or a series of angularly related straight segments, but the changes of direction between such segments are not so sharp as to produce substantial amounts of flow separation, such as eddy currents, and preferably produce no significant amounts of such separation. A bend with zero torsion is planar, and a bend with torsion is non-planar.

"Bent" refers to a duct or portion of a duct that has a bend for a centerline.

"Centerline," a feature of a confined stream or of an

internal fluid enclosing portion of a duct, is the locus of the middle points of all its cross-sections.

"Centrifugal acceleration field" is a field of acceleration generated within flowing fluid by curvature and torsion of its streamlines. The magnitude of other accelerations affecting the fluid and/or its contents, whether such accelerations are of internal and/or external origin, may be and preferably are substantially insignificant compared to said centrifugal acceleration. The centrifugal force applied to a particle is the product of multiplying the centrifugal acceleration by the difference in mass between the particle and the corresponding volume of the fluid.

"Coalescence" of particles, which includes agglomeration or coagulation, is any mechanism whereby particles become either a portion of other particles or a portion of clusters of particles. Coalescence may result from collision of particles moving in a carrier fluid, such as by motion of larger and of smaller particles at different velocities. Liquid and solid particles exist which are "coalescible", such as droplets in an emulsion or agglomerative particles of solids such as carbon black, and others which are "non-coalescible". Some non-coalescible particles can be wetted by coalescible liquids and may thus become coalescible. Coalescence is to be understood as being part of the physical and/or chemical reactions which may be caused to take place within the process according to the invention.

"Congruent" is used to convey simultaneously both a specific and more general meaning. In its specific sense it refers to shapes of ducts, duct elements and three-dimensional geometric envelopes within which ducts may be contained, to the nature of flow streamlines and/or to clustering abilities resulting from application of a particular geometric method to the shaping of duct structures, and to the method itself.

That method is disclosed hereinafter. In its more general sense, "congruent" includes shapes, streamlines and clustering abilities not corresponding exactly with those produced by said method, but which to a substantial extent have similar capabilities. The method in question is referred to as "congruent displacement of a figure." It is the displacement of a figure composed of points, each of which has coordinates x,y,z of a definite value, in a rectangular coordinate system with a center O and axes O_x, O_y, O_z. The coordinate system and the figure which it contains are displaced along a generating line through a succession of positions in which axes O_x, O_y, O_z remain parallel to their prior positions, while maintaining the center O of the coordinate system on the generating line and while maintaining the coordinates of all points in the figure constant within the displaced coordinate system. In a preferred embodiment referred to as "specifically congruent displacement," the shape of the figure, the distances between the respective points and their coordinates remain constant during such displacement, and the area of the figure will also remain constant if the figure is planar and closed. However, it is possible to devise useful embodiments of the invention in which displacement is accompanied by variation of the area of the figure if it is planar and closed, and/or of the shape of the figure, and/or of the distances between the respective and/or of any or all of the coordinates x,y,z of the figure. Thus, for example, the invention contemplates that part or all of the displacement may be "modified scale congruent displacement" of a closed figure, which means that said distances and coordinates may be multiplied, for any given displacement, by a linear or non-linear function or constant factor, including factors differing from unity. The word "substantially," when linked with "congruent" or "modified scale congruent displacement" means that the congruence is not required to be specifically congruent displacement; that is, the coordinate axes of the displaced

figure may be at some angle with those of the figure before displacement, and/or the shape of the displaced figure may differ somewhat from the shape of the figure before displacement, and/or the area of the displaced figure may differ somewhat from the area of the figure before displacement, and/or other characteristics of the figure or displacement may differ somewhat from specifically congruent displacement, if the resultant duct has to a substantial extent flow streamlines and/or clustering and/or other capabilities conforming to or approximating those of ducts formed by specifically congruent displacement.

"Cross-section," as applied to a confined stream or to an internal, fluid enclosing portion of a duct, unless explicitly qualified otherwise, means any of its sections by a plane oriented to minimize the area of said sections.

"Curvature," as applied to a line at a given point, corresponds with its mathematical definition, including the definitions of the direction and magnitude of curvature. For instance, the curvature of a regular helix having a radius $\underline{R}$ and a pitch $\underline{2(PI)p}$ has a uniform magnitude $R/(R^2 + p^2)$.

"Figure," unless explicitly qualified otherwise, means either a planar single line, which is preferably closed on itself, or a planar surface having such a line as its borderline.

"Flow shaping" is a step which may be performed upstream or in the first section of an aerodynamic or hydrodynamic separator, and causes fluid to enter the separator or its next section with a given velocity profile or shape. Such velocity profile may include portions with and/or without separated flow.

"Fluid" is a flowable liquid, gas or mixture thereof, which may or may not include dispersed particles.

"Fractionation" of particles means their breaking down into smaller particles, and may be employed in conjunction with sorting particles according to their sizes.

"Gas" includes true gases, vapors and mixtures of the same.

"Geometric," as applied to an envelope, signifies that the envelope is a three-dimensional, intangible shape to which at least a portion of the surface of a duct conforms or substantially conforms. As applied to an envelope and the geometric method disclosed herein, geometric does not imply any necessity for regular geometric forms such as helices, circles, triangles, straight lines or the like.

"Middle point" is the geometric center of gravity of a cross-section.

"Non-axisymmetric," when used to describe the shape of a figure or a cross-section of a duct, refers to a shape that, when the shape is projected on a projection plane and rotated about its axis or center, at least a portion of the projection exhibits a changing orientation; the definition therefore refers to shapes other than perfect circles, circular cylinders and spheres.

"Orthogonal segment" refers to a portion of a straight line which is within the plane of a cross-section, contains the middle point of the cross-section and is at a right angle with the reference segment. The length of the orthogonal segment is the distance between its two points of intersection with the borderline of the cross-section.

"Particles" includes those particles of liquid and/or solid and/or gas which exist as such upon entering the apparatus or process and/or those particles which are generated (first

become liquid, solid or gas) within the apparatus or process, for example when the entering fluid contains no liquid or solid particles but does contain a source from which such particles are generated and become dispersed in the fluid in the operation of the apparatus or process. For example, gas dispersed as a discontinuous phase in a liquid in which it is relatively insoluble may constitute a particle. Moreover, the inner phase of an emulsion, a liquid dispersed as a discontinuous phase in a liquid in which it is relatively insoluble, may constitute a particle. "Particles" also includes particles of liquid, solid or gas generated within the apparatus or process with a size larger or smaller than those particles entering the apparatus or process, and which may for instance be obtained by coalescence of smaller particles or by fragmentation of larger particles.

"Particles that can be separated from the stream" means particles with sufficient size and density to move relative to fluid within the stream in response to a local centrifugal acceleration field and despite local turbulence of the fluid, until they reach a peripheral zone of the stream within the available length of a separator, and also includes those smaller particles which coalesce with larger particles during motion of the latter.

"Pitch factor" of an helix, also referred to as p, is the pitch P divided by 2(PI).

"Primary flow," a characteristic of fluid flowing in an elongated duct, refers to a flow, or to that portion of a flow, which extends in the direction of elongation of the duct. Although particles, when present, may move relative to the flowing fluid, "primary flow" applies only to the motion of the flowing fluid.

"Primary motion," an attribute of a fluid flowing in an elongated duct, refers to that component of the motion of the fluid which extends in the direction of elongation of the duct.

"Pseudo-", when used to qualify a shape like helicoidal, helico-spiral and/or spiral, means that the corresponding curve is generated in a way similar to that of the specified shape, but with a (periodically or not) variable radius and/or pitch and/or center(s). For instance the projection of a pseudo-helix on a plane perpendicular to its axis may, instead of a circle, be an ellipse, or a triangle, or a square, or a rectangle, or a polygon, or a spiral, or any closed, substantially closed or open curve of any shape surrounding the axis. A pseudo-spiral may be composed of successive segments of ellipses, of triangles, squares, rectangles, polygons, or of any curve.

"Reference plane" refers to a selected plane parallel to a plane that was occupied by a figure during its congruent displacement, or to a selected plane perpendicular to the central generating axis or axes of a generally helicoidal duct.

"Reference segment" refers to a portion of a straight line which is within the plane of a cross-section non-parallel to a fixed reference plane, contains the middle point of the cross-section, and is parallel to the fixed reference plane. The reference segment has a length equal to the distance between its two points of intersection with the borderline of the cross-section.

"Secondary motion" refers to components of motion of a fluid imposed on primary motion or flow in an elongated duct in directions transverse to its direction of elongation. These components, as viewed in a succession of transverse cross-

sections of at least a substantial portion of the length of the duct, define curvilinear rotating motion in the fluid and may for example be produced by appropriate curvature of the duct and possibly also by other duct characteristics such as for example variations of one or more of centerline torsion and of cross-sectional shape, area and aspect ratio. These components may also be produced for example by cross-sectional variations or non-homogeneity of the density of the fluid flowing in the duct, caused by the action of streamlines on denser particles dispersed within this fluid. Such rotating motion, being translated in the downstream direction in the duct by the primary flow results in single or multiple vortices (including swirls) that fill substantially all or part of the transverse cross-section of the duct. The vortices of a secondary flow superposed on a primary flow are not to be confused with microscopic vortical motion which characterizes turbulent flow, which usually will also be present in the operation of the invention. Neither are they to be confused with longitudinal vortices which rotate about an axis perpendicular (and thus not parallel) to the primary flow.

"Secondary flow," a characteristic of fluid flowing in an elongated duct with a secondary motion, refers to that portion of the flow which extends transversely relative to the direction of elongation of the duct. Although particles, when present, move relative to the flowing fluid, "secondary flow" applies only to the motion of the flowing fluid.

"Separation" of particles dispersed in a carrier fluid is to be understood as their displacement relative to the fluid toward a zone where they become concentrated or accumulated, irrespective of their size. Separation may be practiced in conjunction or in series with sorting of particles according to their sizes. The desired end product of separation according to the invention may be either the particles which

are or are not separated from the fluid in the process steps described above. Separation includes the breaking of an emulsion.

"Smooth", as applied to the fluid confining wall of a duct, means that the majority and preferably substantially all of the surface of the wall is free from (i) surface roughness of 0.005 mm or more, less preferably 0.01 or more and least preferably 0.03 or 0.05 or more, based on the methodology relected in the data of Table 5-6 and in the text of pages 5-23 through 5-25 of Chapter 5 of Perry's Chemical Engineer's Handbook, R. Perry and D. Green, Editors, 6th Edition, McGraw Hill International Editions (1984) and in other works cited therein, including for instance saw-tooth profiles having these levels of roughness, and (ii) abrupt changes in direction or flow cross-section that would produce substantial amounts of flow separation, such as eddy currents, and preferably produce no significant amounts of such separation.

"Torsion" (and "twist"), as applied to a line at a given point, correspond to the mathematical definition of torsion, including the definitions of the direction and magnitude of torsion. For instance, the torsion of a regular helix having a radius $\underline{R}$ and a pitch $\underline{2(PI)p}$ has a uniform magnitude $p/(R^2 + p^2)$.

"Translation" conveys simultaneously a general and specific meaning which characterizes the flow of a stream of fluid from one position to another, with or without additional changes in condition, such as chemical and/or physical reactions and/or changes of state, such as from gas to liquid. In its more specific sense it refers to flow having cross-sections in which the flow streamlines in substantially all of the area of each cross-section, ignoring those microscopic vortical motions which will be present in

turbulent flow and excluding streamlines in the laminar boundary sublayer thereof, simultaneously have the same velocity and substantially the same direction of motion, and are substantially free of rotational motion about the centerline of the stream. In its more general sense translation refers to flow having cross-sections in which the primary flow streamlines in at least either a major or a substantial portion of the area of each cross-section, ignoring the microscopic vortical motions of turbulent flow and excluding laminar sublayer flow, have generally similar directions of motion, and such flow may or may not also include substantial differences in the primary velocity of the streamlines in the cross-section, and/or minor and/or oscillating rotational motion of the stream about its centerline.

"Twist" or "twisted," as applied to a flow of fluid, refers to flow through a series of cross-sections, the centerline of which has substantial torsion or twist.

Claims

1. Aparatus for translation of fluid flowing along a flow path in a confined stream comprising:
   a. at least one duct that has at least one inlet for receiving fluid, and at least one internal fluid enclosing surface;
   b. said surface defining an elongated fluid passageway, and substantially conforming along at least a substantial portion of its length to a geometric envelope formed by substantially congruent displacement of a planar figure, said displacement occurring along a continuous generating line of finite length which has, at any point of at least a substantial portion of its length, substantial curvature and substantial torsion or twist, a reference point of the plane of said planar figure being retained on said generating line during said substantially congruent displacement; and,
   c. at least one outlet for discharge of fluid.

2. Assemblies comprising arrays of plural ducts for conveying fluids, comprising:
   a. plural ducts having confining walls of one or more component parts for confining and conveying said fluids,
   b. the outer surfaces of the confining walls of a plurality of said ducts having congruent portions of substantial length, the cross-sections and longitudinal profiles of which substantially coincide with or substantially fit within elongated generally three-dimensional congruent geometric envelopes,
   c. said ducts being clustered with said confining wall congruent portions closely adjacent one another laterally in two or more directions and along substantial portions of their respective lengths, and

with at least said substantial portions extending in the same general direction.

3. A method for twisting, pressure-reversal translation of fluid in a duct, comprising:

a. causing said fluid to flow through the duct with a primary component of flow having a primary flow vector extending generally downstream in said duct, which primary flow may or may not be combined with a secondary component of flow and its corresponding vector which is transverse to said primary flow vector,

b. causing said flow to occur in a duct having confining walls and a centerline with both substantial twist and curvature throughout a substantial portion of its length, and having a plurality of cross-sections along said portion of length,

c. shaping the flow of fluid within said portion of the length of the confining walls to create a centrifugal acceleration field with a component generally transverse to the primary flow vector and to produce points of differing pressure across a given cross-section in an upstream portion of the duct, including spaced apart first and second points at which the pressures are at maximum and minimum values respectively and have a substantial positive or negative difference between them, which is referred to as a first difference,

d. causing the fluid to flow in said portion in the downstream direction from the given cross-section through additional cross-sections, the middle points of which define a flow path with a centerline having both substantial curvature and substantial twist, to reduce said pressure difference until it has reversed and has become a substantial difference of opposite sign in a downstream cross-section of the duct;

e. and causing said reduction and sign reversal to occur one or more times along traces extending downstream from the first and second points of the given cross-section through said additional cross-sections and to follow vectors of the primary flow component forward from the first and second points through said additional cross-sections.

4. A fluid translation process comprising: causing fluid to flow along a flow path in a confined stream in at least one duct that has at least one internal fluid enclosing surface that substantially conforms along at least a substantial portion of its length to a geometric envelope, formed by substantially congruent displacement of a planar figure along a continuous generating line of finite length which has, at all points on at least a substantial portion of its length, substantial curvature and substantial torsion or twist, a reference point of the plane of said planar figure having been retained on said generating line during said substantially congruent displacement.

5. A fluid translation process for translating a fluid flowing in a confined stream, comprising:

a. establishing a primary flow composed at least in part of a plurality of substantially congruent primary streamlines in the fluid,

b. conducting the confined stream along an elongated flow path which has, throughout said flow path, a predetermined general direction of flow through successive cross-sections of the flow path in planes perpendicular to said flow direction,

c. inducing a turning motion with substantial curvature and substantial torsion of the primary streamlines for generating within at least a portion of the confined stream a centrifugal acceleration field with

a substantially similar general field direction in at least a portion of said cross-sections, and

d. turning the general direction of this centrifugal acceleration field progressively between said cross-sections by an angle substantially similar to the torsion of the streamlines between said cross-sections.

6. A method for operating aerodynamic or hydrodynamic separators that have a threshold particle size which is the smallest size of particles which the separator can separate with nearly complete efficiency from a dispersion of substantially uniformly sized particles, comprising:

a. conducting a fluid stream containing dispersed particles and/or a source of dispersed particles, including substantial quantities of particles above and below said threshold, in turbulent flow through a helical duct separator,

b. controlling the ratio of particles above and below said threshold in said separator to provide sufficient amounts, of particles above said threshold, to coalesce or agglomerate with the particles that are smaller than the threshold, and cause the smaller particles to be separated with the larger particles with which they have coalesced or agglomerated, and

c. separating particles from the stream.

7. A method for operating aerodynamic or hydrodynamic separators that have a threshold particle size which is the smallest size of particles which the separator can separate with nearly complete efficiency from a dispersion of substantially uniformly sized particles, comprising:

a. conducting a fluid stream containing dispersed particles and/or a source of dispersed particles, including substantial quantities of particles below said threshold, in turbulent flow through a helical duct separator,

b. providing a layer of liquid upon a wall in the helical duct, in or upstream of the separation zone, and

c. causing said layer to flow downstream in the duct in the same general direction as the fluid stream,

d. bringing a substantial portion of the particles below the threshold into contact with and causing them to coalesce with the liquid layer, and

e. separating such particles from the stream with the liquid layer.

8. Apparatus for separating particles from fluid comprising:

a. a duct for imparting motion to a fluid stream along an elongated flow path which has, throughout said flow path, a constant general direction of flow, said duct having a separation zone with an internal wall for confining a fluid stream,

b. said wall including a first portion for inducing a turning motion with substantial curvature and substantial torsion in a plurality of substantially congruent streamlines of a primary flow of said fluid for generating a centrifugal acceleration field within at least a portion of the confined stream,

c. said acceleration field having a substantially similar general direction in at least a portion of each of its cross-sections by planes perpendicular to said general direction,

d. said acceleration field exerting force on said particles in said general direction and turning progressively, as the flow moves downstream through said cross-sections, by an angle substantially

similar to the torsion angle of the streamlines between said cross-sections, and

e. means for collecting the particles from this zone.

9. The subject matter of any preceding claim wherein the duct wall includes a second portion for accumulating sufficient turning motion of the primary flow in the confined stream for causing at least a substantial portion of the total mass of the dispersed particles and/or of the source of dispersed particles that can be separated from the stream to migrate from major portions of said primary flow under the influence of the centrifugal force, toward a predetermined peripheral zone of the duct and to form a particle-rich portion of the primary flow within this zone.

10. The subject matter of any preceding claim wherein the centrifugal acceleration field causes the dispersed particles to move within the confined fluid stream and relative to it in the general direction of said force, thus creating in said confined stream enriched regions having a relatively higher quantity of said particles and depleted regions having a relatively lesser quantity of said particles, said regions developing at least near portions of the boundaries of the confined stream, and the turning of said acceleration field also causes these denser and thinner regions to move similarly to the turning of said field within said confined stream along said flow path, thus creating at least near the boundaries of the stream a secondary flow having a rotational velocity substantially equal to the rotational velocity of the general direction of the centrifugal acceleration field.

11. The subject matter of any preceding claim wherein the duct wall includes a first portion for generating a

secondary flow in said confined stream with said turning motion, said secondary flow comprising a swirl having substantial components of rotational velocity transverse to the flow path, said wall having a second portion for accumulating sufficient turning motion of the primary flow in the confined stream for causing at least a substantial portion of the total mass of the dispersed particles that can be separated from the stream to migrate from major portions of the stream under the influence of centrifugal force, generated at least partially and substantially by secondary flow, toward a predetermined zone of said duct and to form a particle-rich portion of said stream within said zone.

12. The subject matter of any preceding claim wherein the inner cross-sectional shape and/or area of the duct is varied to cause an increase of the rotational velocity of the centrifugal acceleration field as the fluid flow progresses along its pathway.

13. A process for aerodynamic or hydrodynamic separation of components from a fluid, comprising:
   a. establishing a primary flow composed of a plurality of substantially congruent primary streamlines in a confined stream, containing dispersed particles and/or a source of dispersed particles, of a fluid flowing along an elongated flow path having along its full length a general direction of flow;
   b. inducing within said confined stream, along at least a portion of said flow path, a turning motion of said primary streamlines including substantially similar curvature and torsion among said streamlines, for generating a centrifugal acceleration field having a substantially similar general field direction in at least a portion of each of its cross-sections by planes perpendicular to said general flow direction;

c. causing the general direction of the centrifugal acceleration field to turn progressively as the flow passes between said cross-sections by an angle substantially similar to the torsion angle of the primary streamlines between said cross-sections, thus shaping the flow for subsequent centrifugal separation of said dispersed particles; and

d. subsequently separating centrifugally and collecting at least a substantial portion of the total mass of the dispersed particles that can be separated from the flow.

14. The subject matter of any preceding claim including accumulating sufficient turning motion of the primary flow in said confined stream for causing at least a substantial portion of the total mass of the dispersed particles and/or of the source of dispersed particles that can be separated from the stream to migrate from major portions of said stream under the influence of said centrifugal force, toward a predetermined peripheral zone of said duct and to form a particle-rich portion of said stream within said zone.

15. The subject matter of any preceding claim including continuing said turning motion for causing the centrifugal force induced by said acceleration field in said dispersed particles to move said dispersed particles within said confined fluid stream in the general direction of said force, thus creating in said confined stream denser regions enriched in at least a portion of said particles and thinner regions depleted in at least a portion of said particles, said regions developing at least near portions of the boundaries of said confined stream; causing said turning of the field of said centrifugal force to move said denser and said thinner regions similarly to the turning of said field

within said confined stream along said flow path, thus creating at least near the boundaries of said stream zones of fluid a secondary flow having a rotational velocity substantially equal to the rotational velocity of said general direction of said centrifugal acceleration field.

16. The subject matter of any preceding claim including establishing a primary flow of a fluid flowing along a flow path in a confined stream containing dispersed particles and/or a source of dispersed particles; inducing a turning motion in said primary flow for generating in said confined stream a secondary flow comprising a swirl having substantial components of rotational velocity transverse to said flow path; and accumulating sufficient turning motion of the primary and secondary flow in said confinement member through a substantial total angular interval for causing at least a substantial portion of the total mass of the dispersed particles and/or of the source of dispersed particles that can be separated from the stream to migrate from major portions of said confined stream under the influence of centrifugal force, generated at least partially and substantially by said secondary flow, toward a predetermined zone of said confinement member and to form a particle-rich portion of said stream within said zone.

17. The subject matter of any preceding claim including causing the general magnitude of said centrifugal acceleration field and/or its rotational velocity to increase while the fluid flow progresses along its path.

18. The subject matter of any preceding claim including establishing said primary flow with a fluid containing dispersed particles or a source of dispersed particles,

including particles of about two microns or less in particle size that can be separated from the stream; accumulating sufficient turning motion of the primary flow in said confined stream through a total angular interval of at least about 720 degrees while continuing downstream along said flow path and for causing at least 90% of all particles having a particle size in the range of about 1.5 to about 2.5 microns, or about 0.75 to about 1.25 microns, or about 0.35 to about 0.65 microns, to migrate from said stream under the influence of said centrifugal force toward said predetermined zone, and recovering said particles.

19. The subject matter of any preceding claim wherein a plurality of matingly compatible congruent ducts are stacked in a close-fitting cluster with their outer surfaces adjacent to each other in one, two or three directions.

20. The subject matter of any preceding claim wherein a plurality of ducts are arranged in one or more clusters in which congruent ducts are closely adjacent laterally along substantial portions of their length, in two or more directions.

21. The subject matter of any preceding claim wherein the ducts have side or top and bottom walls which are an array of webs of undulating cross-section arranged in generally parallel, spaced apart relationship and having ridges and valleys in the surfaces thereof, the remaining walls of the ducts are formed of pluralities of spacers of undulating cross-section that are arranged generally parallel to one another in the spaces between said webs and perpendicular to said webs and to the ridges thereof, and said spacers have margins with traces that conform to the surfaces of the webs and are secured in close fitting

engagement with the web surfaces to form helical passageways.

22. The subject matter of any preceding claim wherein the respective ducts have walls with no substantial lateral spacing between them.

23. The subject matter of any preceding claim wherein said ducts include one or more walls which are distinct from or shared with other adjacent ducts.

24. The subject matter of any preceding claim wherein said ducts include walls which are spaced a short distance apart and are distinct walls to provide for circulation of fluid about the exteriors of the duct.

25. The subject matter of any preceding claim including a corrugated cluster translator comprising:

a. a cluster of plural rows and columns of elongated passageways, defining elongated, fluid flow paths for primary flows of streams of fluid which may be conducted through them,

b. said passageways having walls formed of webs of material of undulating cross-section, that undulate along the length of the flowpaths,

c. said webs having ridges and valleys which, when viewed in plan view, extend at one or more angles that are skewed relative to major portions of the lengths of the flow paths, and are spaced apart from one another by distances which are sufficiently small in two or more directions to promote undulation of the primary flows in each of two or more directions transverse to the flow paths in the passageways.

26. The subject matter of any preceding claim wherein a portion or at least a substantial plurality or

preferably all the passageways in the cluster, have one or more of the following characteristics or features:

- cross-sections in planes perpendicular to the general direction of flow that are of different or varying shapes; and/or
- centerlines substantially similar to a helical curve; and/or
- fluid flow paths with aspect ratios that increase and decrease along the length thereof in conjuction with said undulations; and/or
- lateral and vertical contiguity, so that the flow paths are juxtaposed in a way leaving substantially no unused space between them.

27. The subject matter of any preceding claim wherein the ducts have one or more of the following characteristics or features:
    - the walls of three or more passageways in a plurality of rows and/or columns of the cluster are different portions of the same or common webs; and/or
    - the passageways have lower, side and upper walls each formed of webs of material of undulating cross-section; and/or
    - the ridges of the webs of the side walls are non-co-planar with and at substantial angle of divergence relative to ridges of the webs of the lower and upper walls; and/or
    - the webs have substantially rectilinear ridges and valleys; and/or
    - the duct internal surfaces are each made of four assembled webs, each web being at least a portion of a corrugated plate, including a pair of vertical webs and a pair of horizontal webs, said pairs being engaged at the surfaces of one of said pairs and along the longitudinal edges of the other pair; and/or

- the passageway walls are stacks of, alternatively, (a) plates with undulating surfaces having ridges extending in a first direction and (b) pluralities of spacers arranged between the plates with ridges extending in a second direction which is at an angle to the first direction, said spacers having margins whose projected marginal edge traces and surfaces conform to the undulating surfaces of the plates and and are in close-fitting engagement therewith; and/or
- the duct walls are composed of stacks of alternating corrugated plates and spacers, said plates having surface undulations with the shape of a first periodic curve, and the spacers having surface undulations with the shape of a second periodic curve similar but transverse to said first periodic curve; and/or
- the webs have an undulating cross-section substantially similar to a sine and/or cosine curves; and/or
- the duct walls are essentially composed of two sets of parts, all parts in each of said sets being identical.

28. The subject matter of any preceding claim wherein at least a substantial plurality of the passageways in the cluster have inlets for receiving said fluid with dispersed particles and/or a source of dispersed particles, and
- the passageways subject these particles to centrifugal forces that concentrate the particles in one or more zones adjacent one or more of said walls.

29. The subject matter of any preceding claim including cluster translators with passageways having one or more of the following characteristics:

- walls formed of webs having channels with non-rectilinear ridges and valleys extending in a given direction in said webs, said channels having undulations along their length, extending in another direction in said webs which is transverse to said given direction; and/or
- undulating cross-sections that are characterized by non-rectilinear ridges and valleys having an undulating shape along their length and, when viewed in plan view, have ridges and valleys which extend at one or more angles that are skewed relative to major portions of the lengths of the flow paths; and/or
- confronting sets of walls including lower and upper walls located one above another, each formed of webs of material of bi-directionally undulating cross-section, the ridges of the lower walls being adjacent or contiguous with and tangent to the valleys of the upper wall; and/or
- being composed of a set of similar or identical bi-directionally corrugated plates forming an array of clustered congruent ducts.

30. The subject matter of any preceding claim wherein the duct has one or more of the following features:
- at least one bent portion the centerline of which has a curvature and/or a torsion increasing in the direction of the flow, and/or
- a progressively modified cross-sectional shape or area, and/or
- a general helicoidal and/or pseudo-helicoidal and/or helico-spiral and/or pseudo-helico-spiral and/or spiral and/or pseudo-spiral shape; and/or
- increasing the curvature of at least a portion of the streamlines of the flow path as the flow progresses; and/or

- increasing the torsion of at least a portion of the streamlines of the flow path as the flow progresses; and/or
- modifying the shape and/or reducing the size of the cross section of the flow path as the flow progresses; and/or
- a flow path for the primary streamlines in the confined stream which comprises:

  (A) a first portion in which both the curvature and the torsion of said streamlines are small as compared with the inverse of the hydraulic radius of the corresponding cross-section of the flow path;

  (B) a second portion in which the turning of the streamlines does not exceed one turn and wherein both their curvature and their torsion are substantially similar to the inverse of the hydraulic radius of the corresponding cross-section of the flow path; and

  (C) a third portion wherein the length of the streamlines is equal to a large number of times the hydraulic radius of the cross-section of the streamlines at the inlet of said third portion and wherein both the curvature and the torsion of the streamlines are small as compared with the inverse of the hydraulic radius of the corresponding cross-section of the flow-path.

31. The subject matter of any preceding claim wherein

    a. a confined stream includes gas carrying a condensable vapor and undergoes in a first portion of its path an expansion by acceleration causing at least a portion of said vapor to condense in the form of small liquid particles dispersed in the thus accelerated gaseous stream and having a size sufficient for permitting their separation by the process;

b. the confined stream thus obtained then enters a second portion of its path where it undergoes separation of a substantial part of the condensed particles with or without further expansion by acceleration and/or at least partial recompression by deceleration; and

c. the confined stream thus obtained undergoes in a third portion of its path a recompression by deceleration.

32. The subject matter of any preceding claim including one or more of the features of:

- atomizing droplets of a liquid in a fluid for exchanging heat and/or mass with said fluid; and/or
- fractionating the atomized droplets to droplets of a smaller size in a portion of a flow path where centrifugation occurs; and/or
- causing atomized and/or fractionated droplets to react physically and/or chemically with a flowing fluid during their centrifugation; and/or
- causing physical and/or chemical reaction between fractionated droplets and a fluid stream to take place substantially in a portion of a flow path where centrifugation but little separation of the fractionated droplets are caused to occur, said separation being caused to occur in a subsequent portion of the flow path.

33. The subject matter of any preceding claim wherein the internal fluid enclosing surface of the duct has a center line which extends longitudinally in the duct; within at least a substantial portion of the length of the duct, said centerline is defined by the middle points of an infinite number of duct inner cross-sections in planes that are oriented to minimize the areas of the respective cross-sections and when viewed in

a succession of said cross-sections at progressively and longitudinally advanced positions along a substantial portion of the length of said centerline, the fluid enclosing surface exhibits substantial variation of the aspect ratio of said cross-sections.

34. The subject matter of any preceding claim wherein at least a portion of said continuous generating line has substantial curvature and twist, and the curved and twisted portion of the generating line has the form of a portion of an helix or pseudo-helix or an helico-spiral or a pseudo helico-spiral, or a non-helical form.

35. The subject matter of any preceding claim wherein the geometric envelope is generated by a helical or non-helical generating line with portions having substantial curvature and substantial twist, and the resultant duct represents a substantial fraction or an integer or non-integer multiple of a complete turn.

36. The subject matter of any preceding claim wherein the duct includes non-curved portions.

37. The subject matter of any preceding claim wherein the geometric envelope is generated by displacement of a curved figure.

38. The subject matter of any preceding claim wherein the geometric envelope is a circular figure.

39. The subject matter of any preceding claim wherein the cross-section of the confined stream by a plane perpendicular to said general direction of flow is substantially circular.

40. The subject matter of any preceding claim wherein the planar figure is a triangle, square, rectangle, parallelogram, octagon, hexagon or other polygonal shape, a portion of the foregoing or irregular shapes.

41. The subject matter of any preceding claim wherein the duct(s) has/have circumferences as cross-sections perpendicular to the axis of the generating helix and one or more zones generated by such cross-sections which are non-axisymmetric at intervals along its length, and preferably including at least one such zone within the first turn of the generating helix.

42. The subject matter of any preceding claim wherein the fluid contains dispersed particles and/or a source of dispersed particles, in which progressive turning of a centrifugal acceleration field between said cross-sections shapes a flow of said fluid and dispersed particles for subsequent centrifugal separation of said particles, and in which at least a substantial portion of the total mass of the dispersed particles that can be separated from the flow are subsequently separated centrifugally and collected.

43. The subject matter of any preceding claim in which a major portion of the particles below the threshold size are separated in a single pass through the separator.

44. The subject matter of any preceding claim wherein a substantial quantity of relatively larger particles having a size above said threshold are introduced into or generated in the stream, during or prior to the flowing of the stream through the duct and prior to completion of particle separation.

45. The subject matter of any preceding claim wherein the feed to the helical separator is either dispersed particle-containing fluid effluent from an upstream separator or a fraction derived from the feed flow of the latter separator mixed with its fluid effluent, discharging the requisite proportions of particles of the required sizes.

46. The subject matter of any preceding claim wherein any particles which may be present include particles of liquid and/or solid and/or gas which exist as such upon entering the apparatus or process and/or which are generated within the apparatus or process.

47. The subject matter of any preceding claim wherein substantially all of the surface of the fluid confining wall of the duct, is free from surface roughness of 0.05 mm or more, and from abrupt changes in direction or flow cross-section that would produce substantial amounts of flow separation, such as eddy currents.

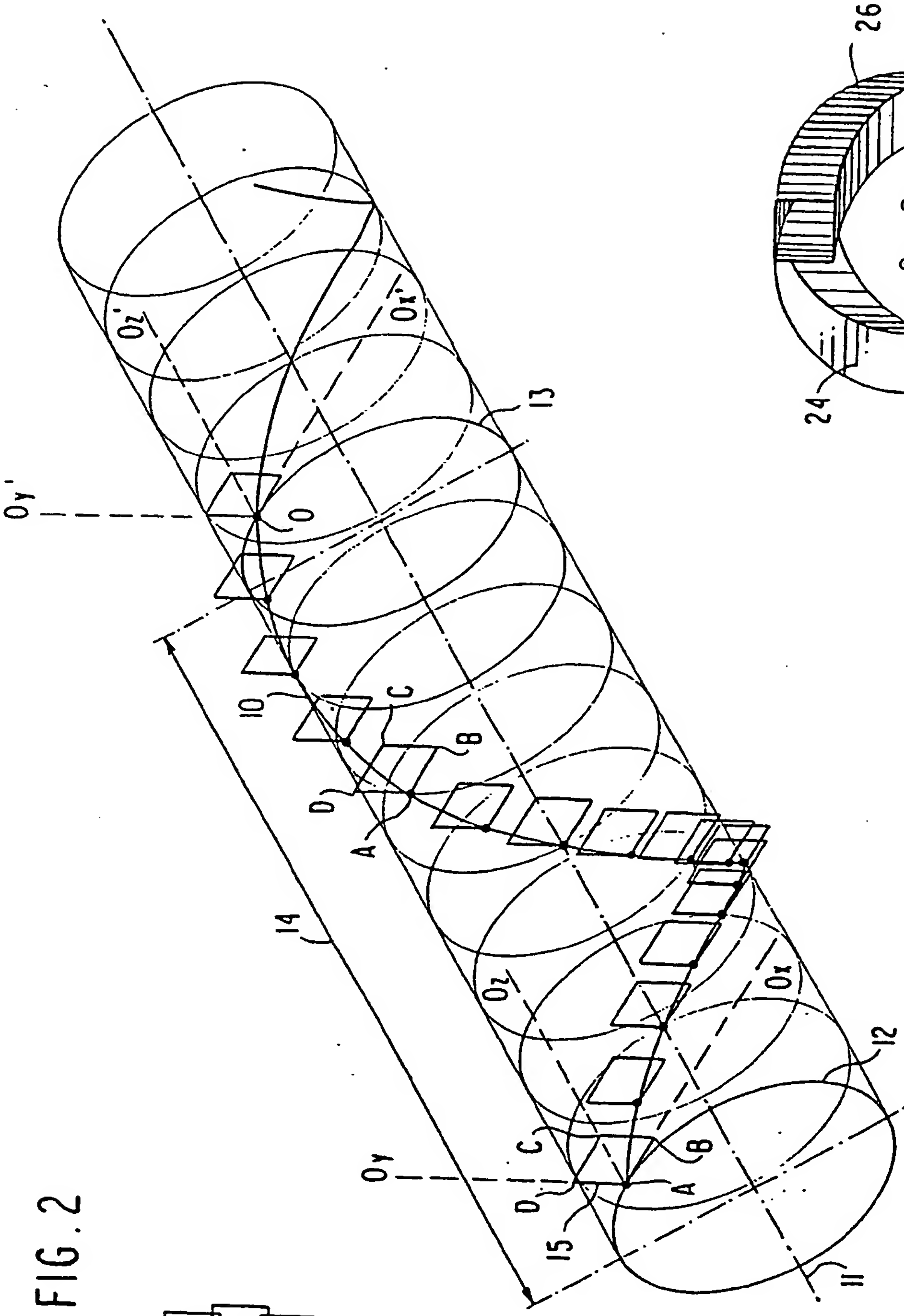


FIG.1

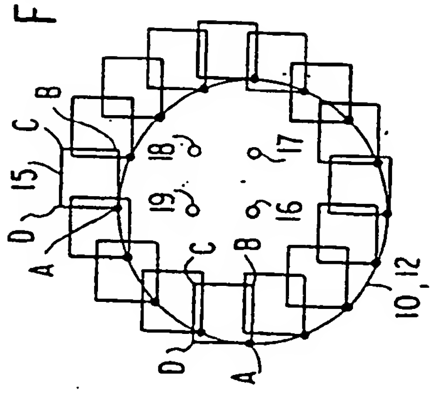


FIG.2

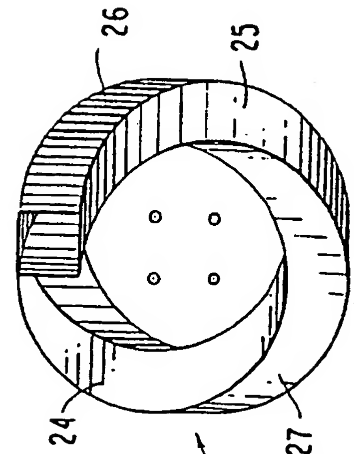


FIG.3

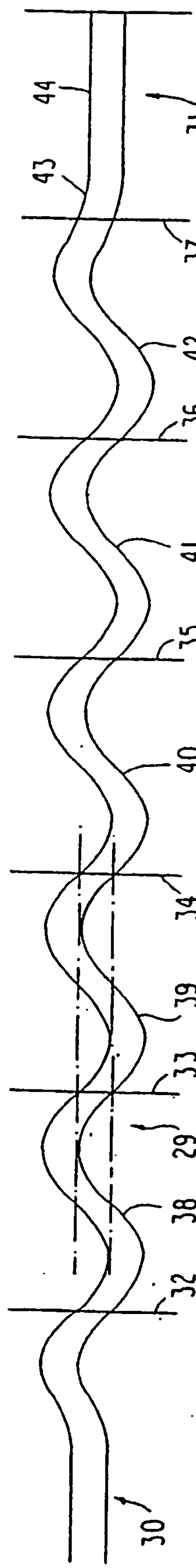


FIG.5

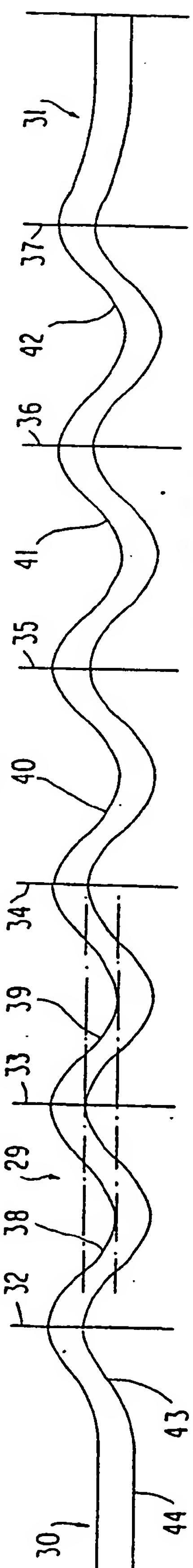


FIG.6

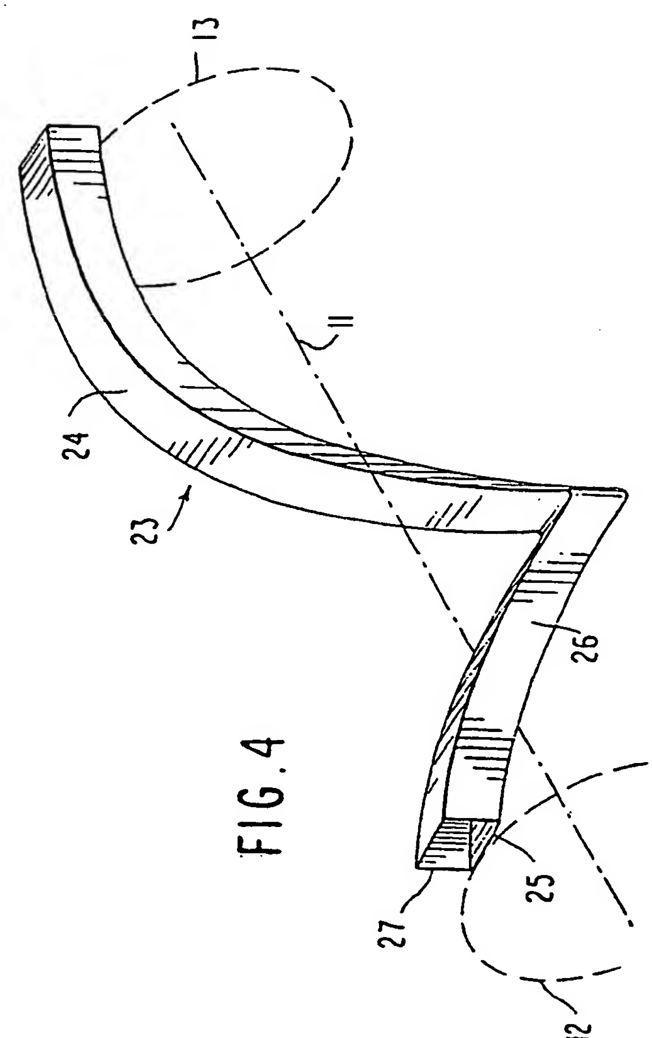


FIG.4

FIG.7A

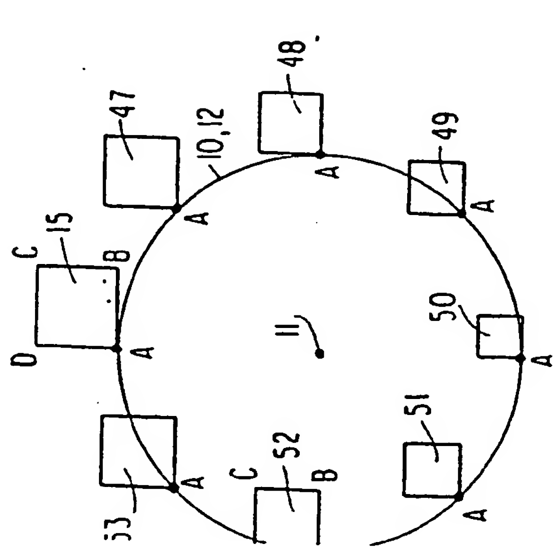


FIG.7B

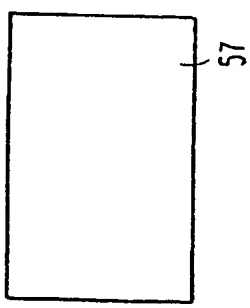


FIG.7C

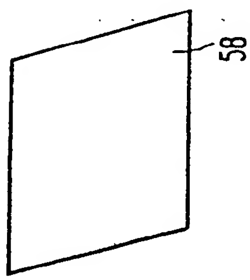


FIG.7D

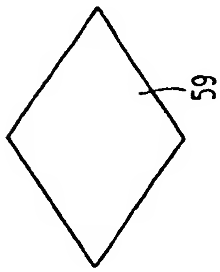


FIG.7E

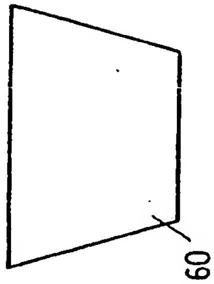


FIG.7F

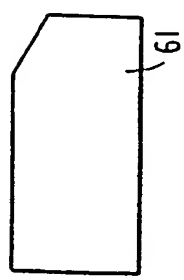


FIG.7G

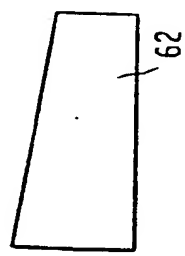


FIG.7H

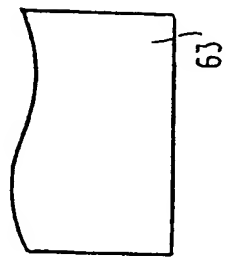


FIG.7I

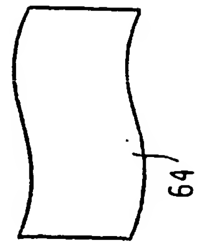


FIG.7J

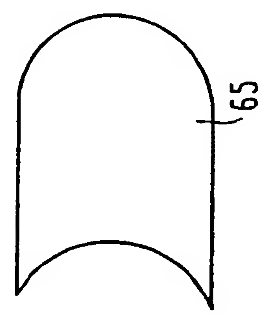


FIG.7K

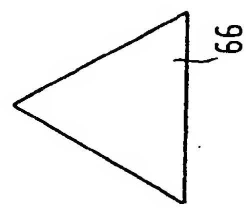


FIG.7L

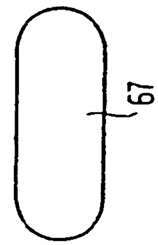
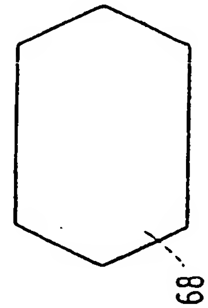


FIG.7M



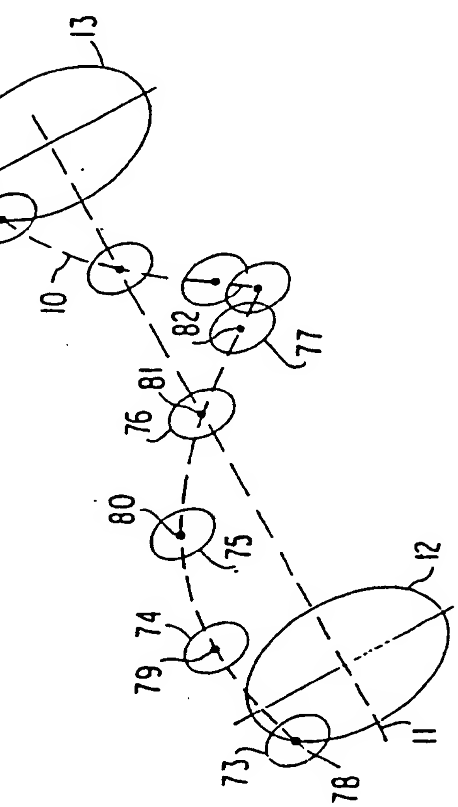


FIG.8A

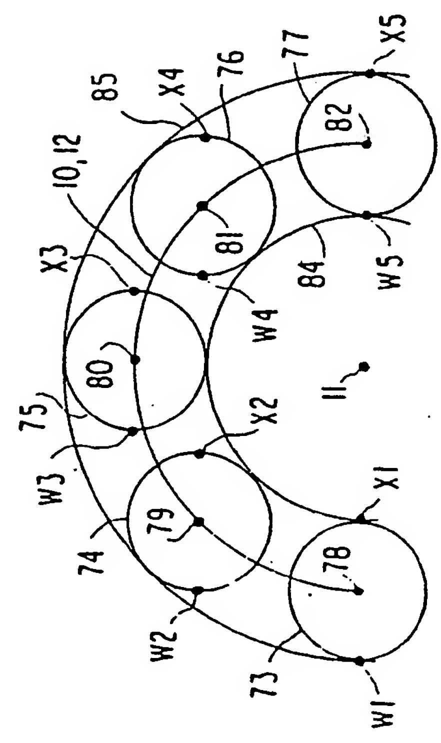


FIG.8B

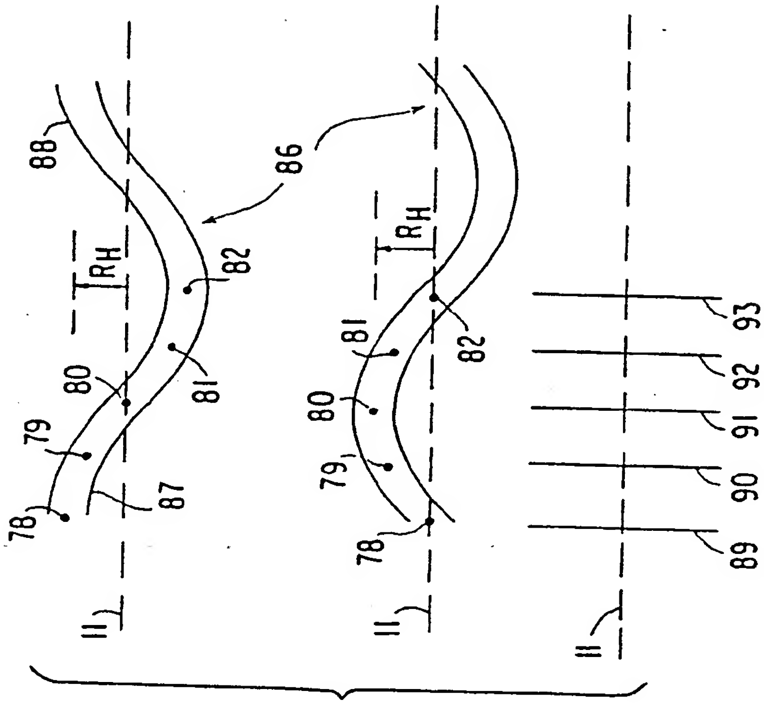


FIG.8C

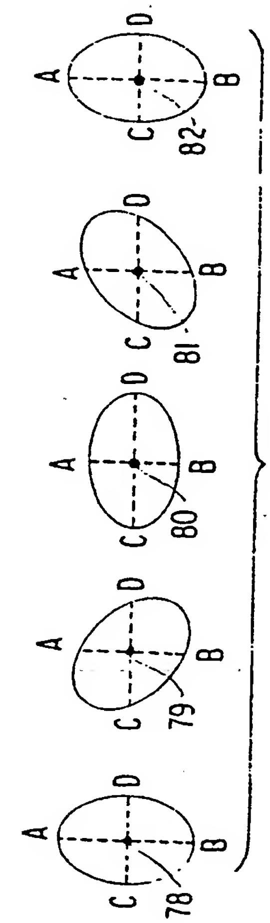


FIG.8D

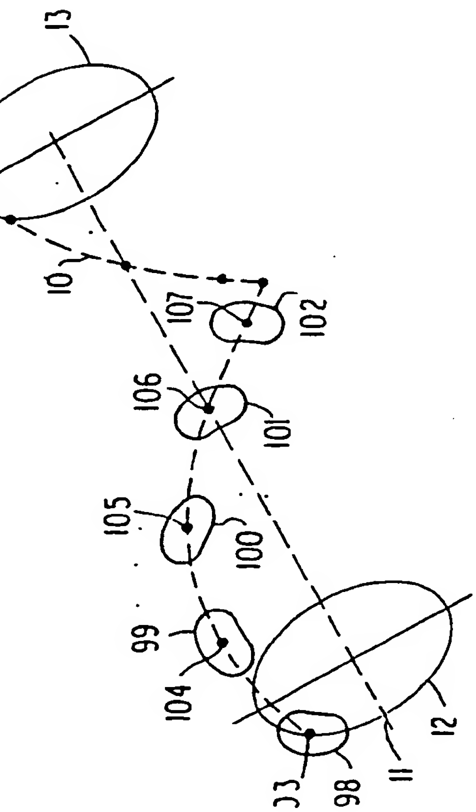


FIG. 9A

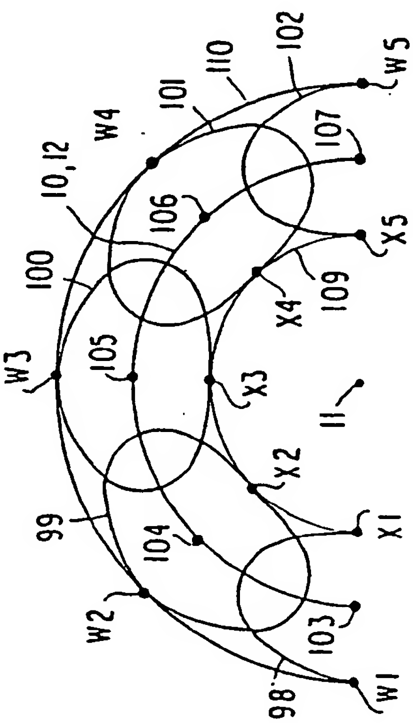


FIG. 9B

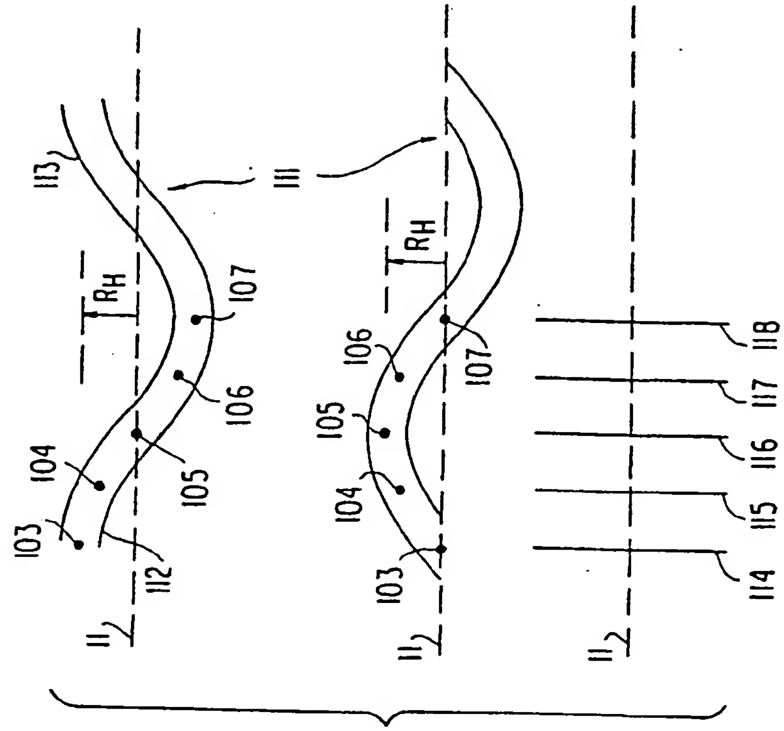


FIG. 9C

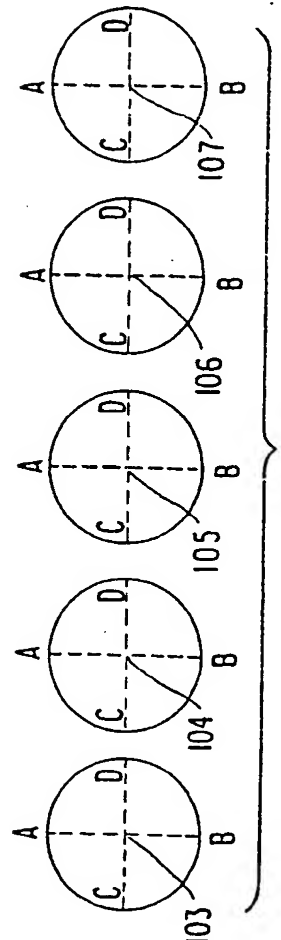


FIG. 9D

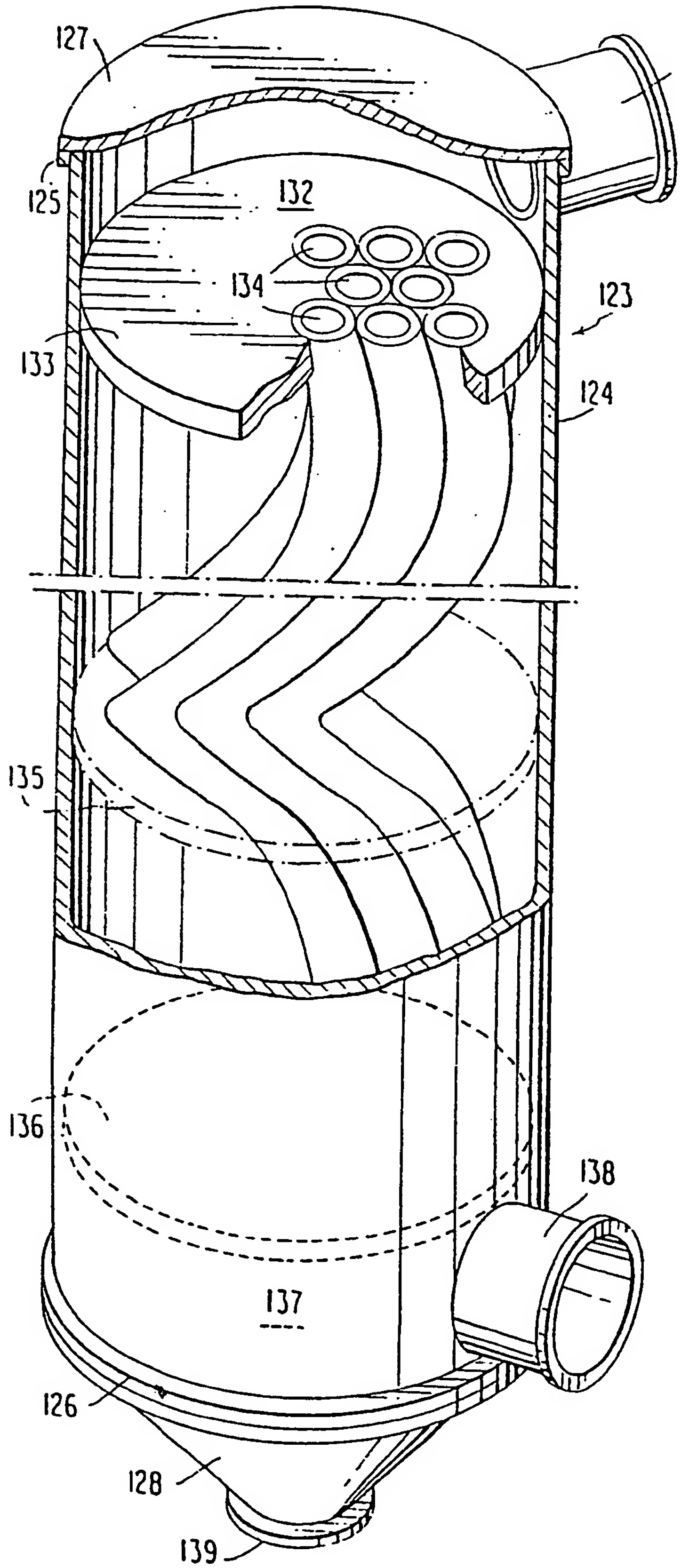
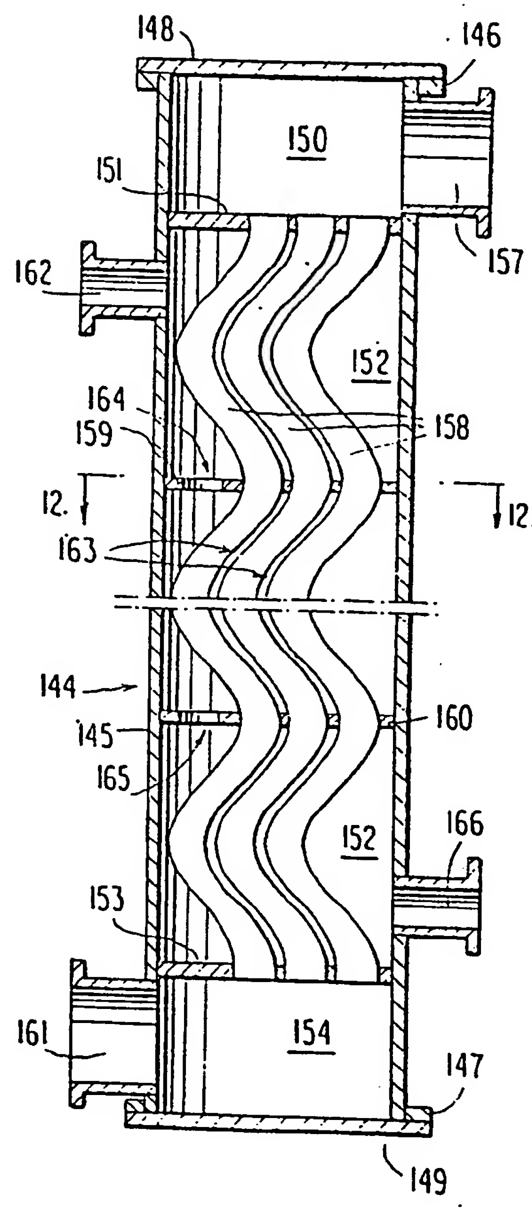


FIG.10

FIG.11



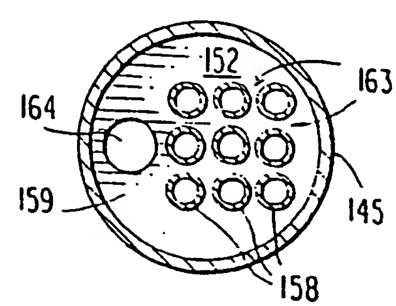
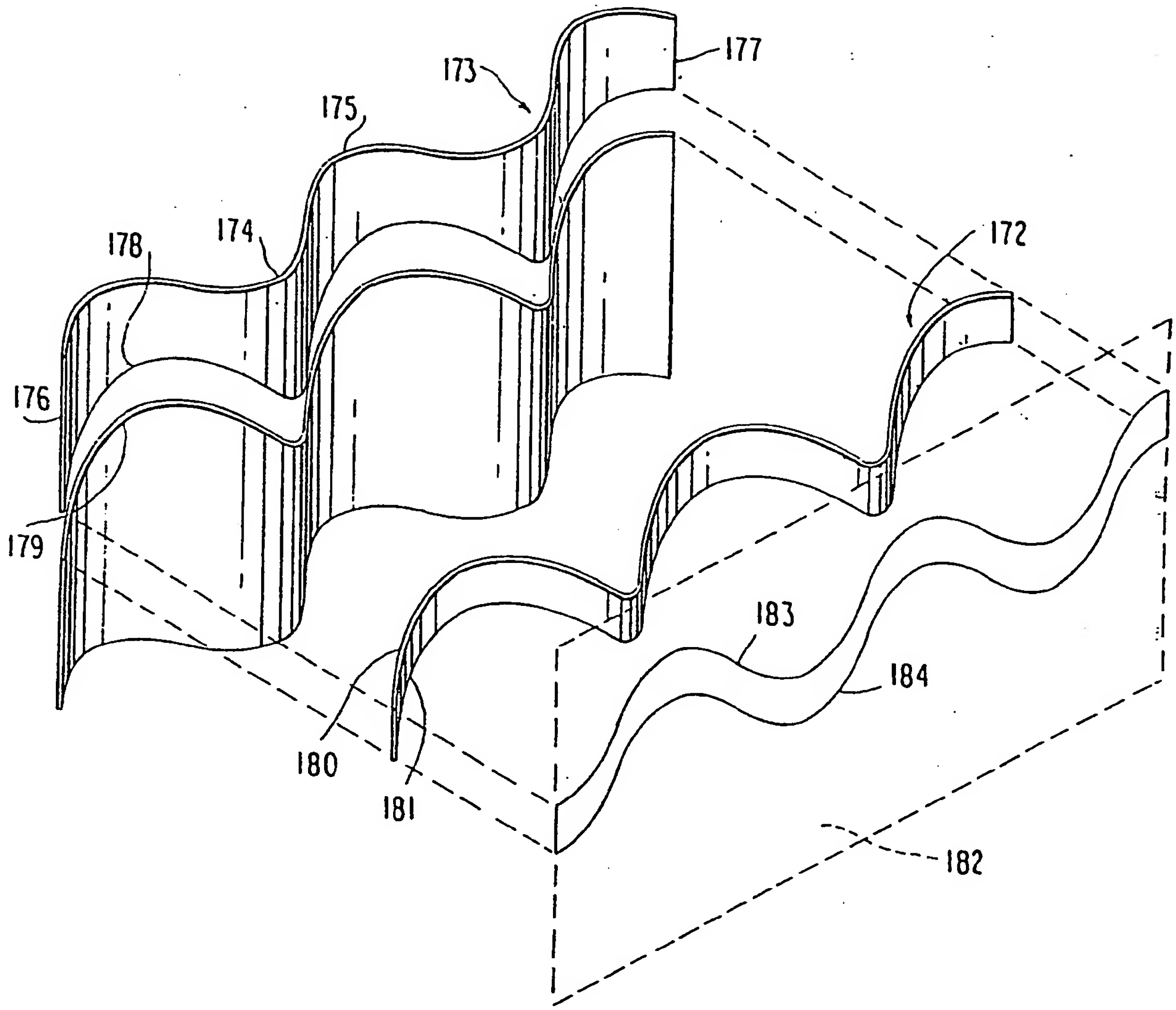


FIG.12

FIG. 14



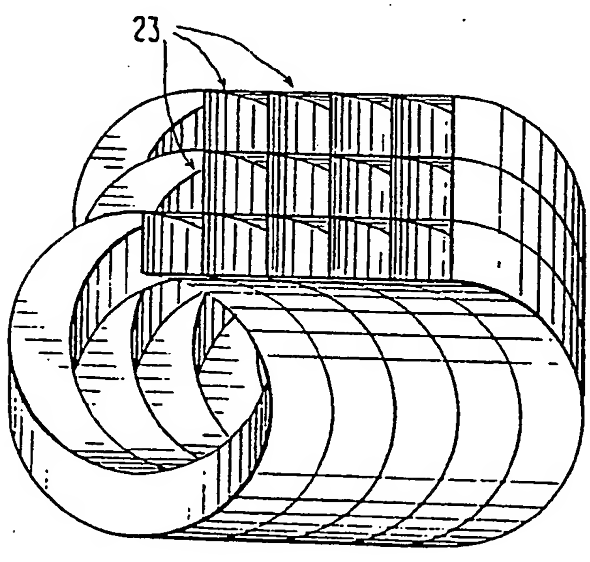


FIG. 13

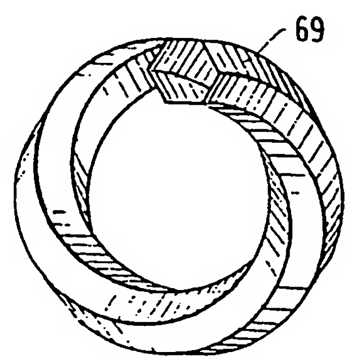
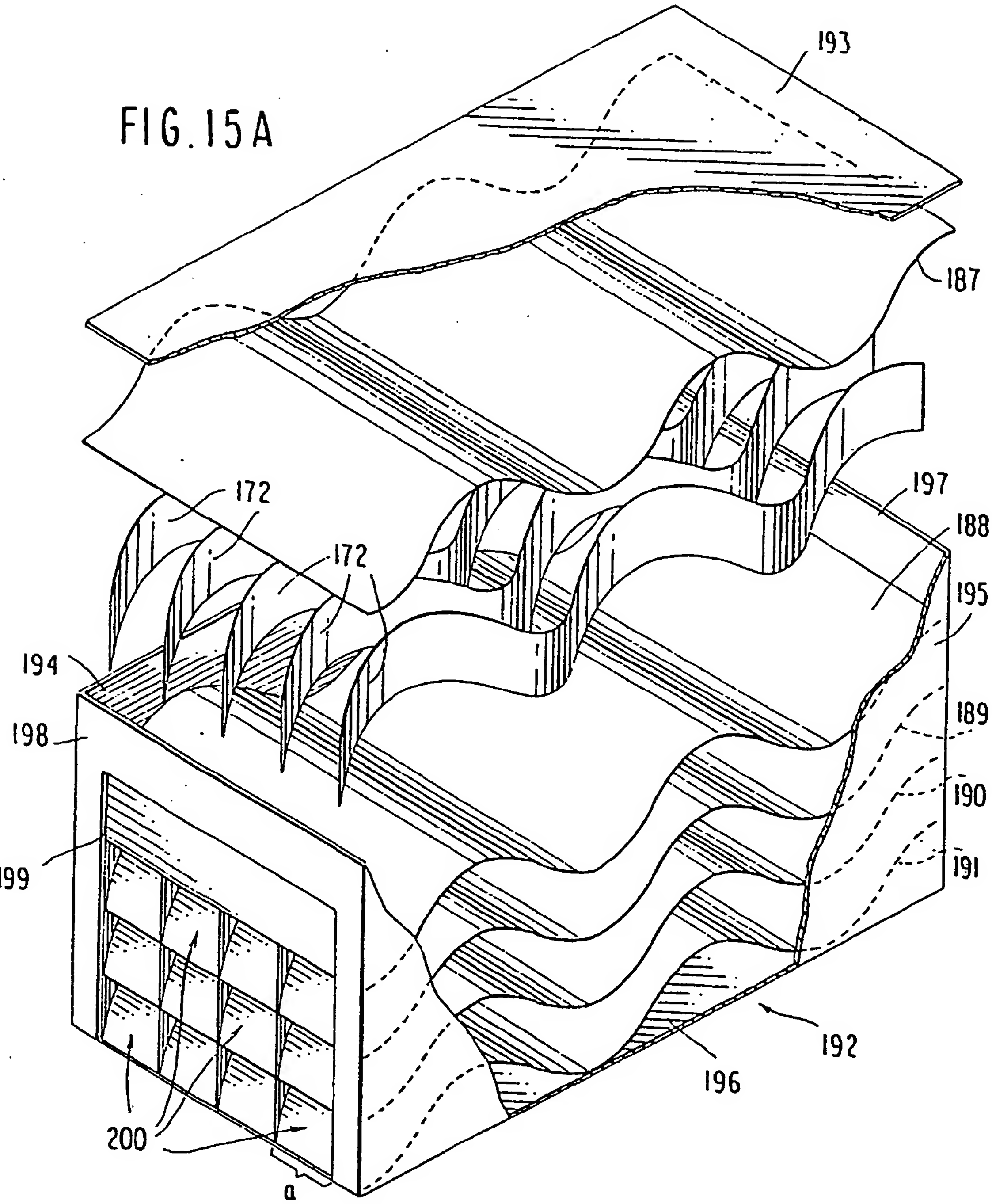


FIG. 7N

FIG. 15A



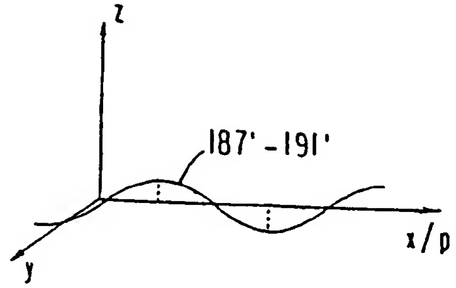


FIG. 15B

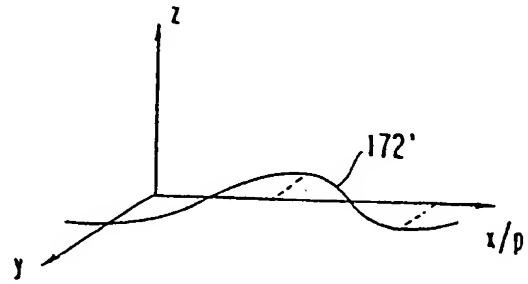


FIG. 15C

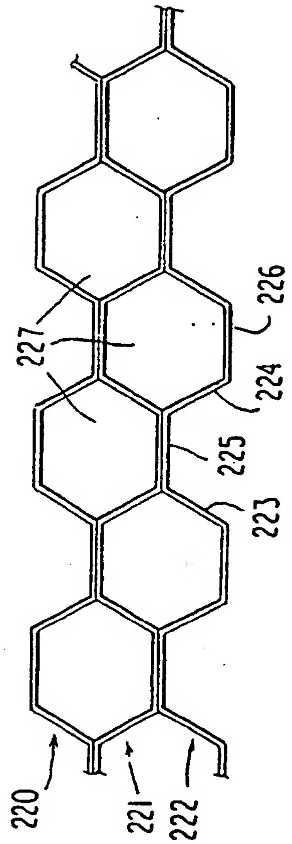


FIG.18

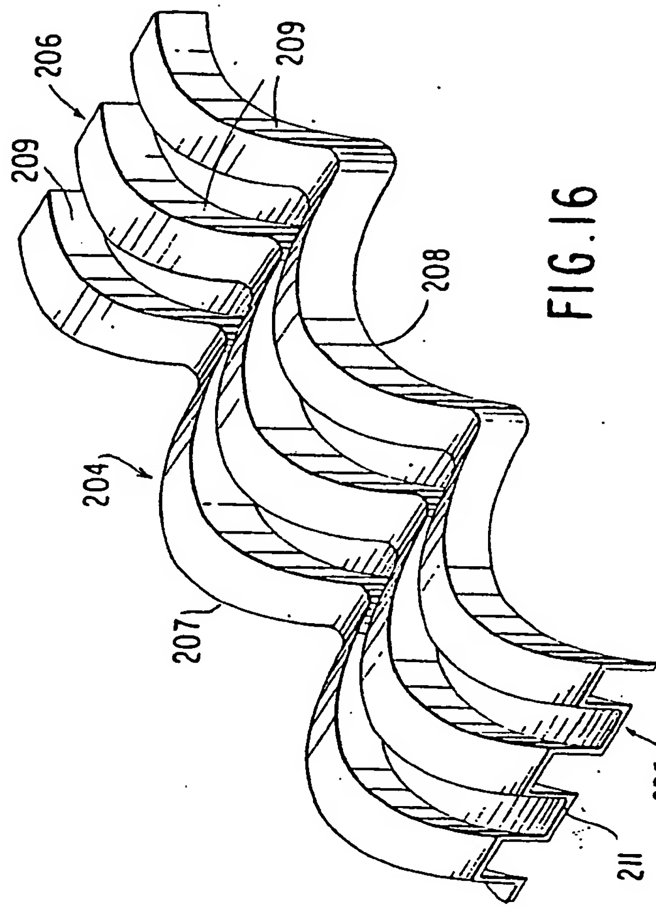


FIG.16

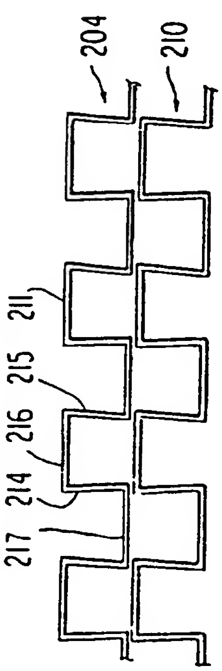


FIG.17

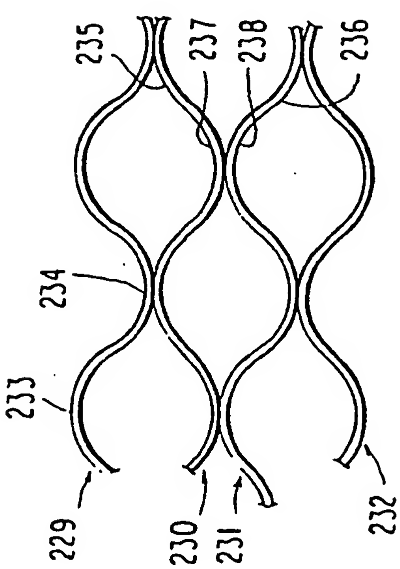


FIG.19

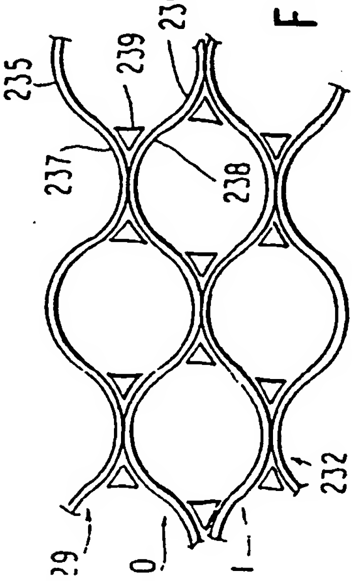


FIG.20

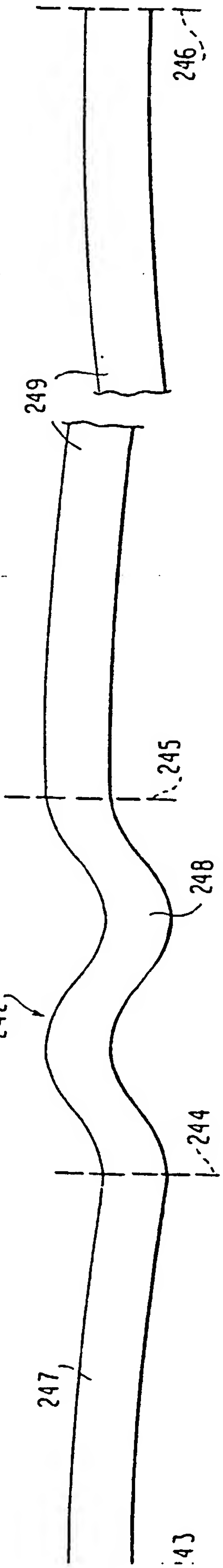


FIG. 21

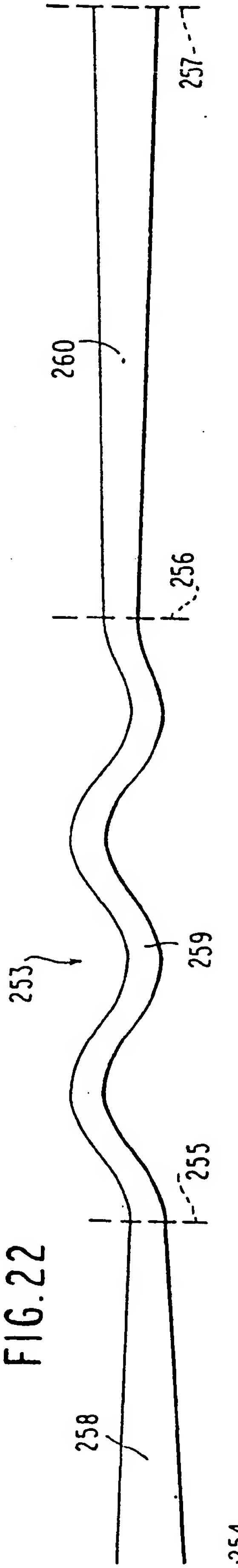


FIG. 22

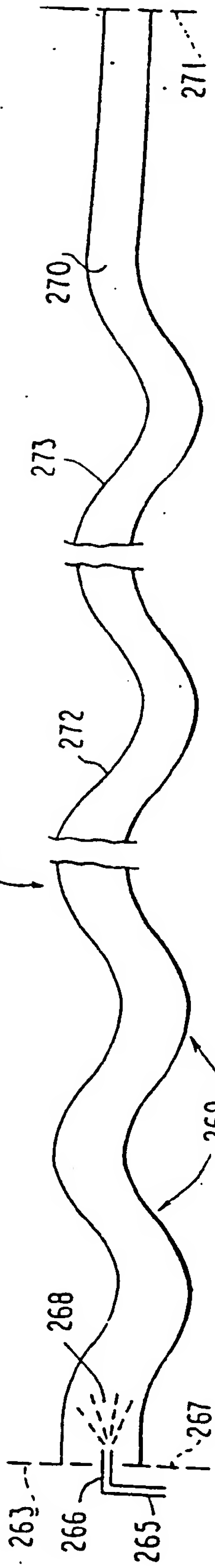


FIG. 23

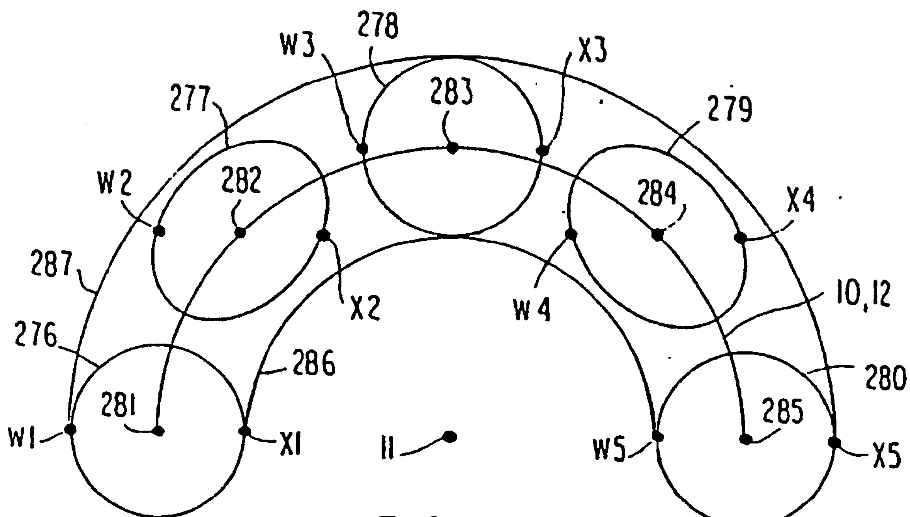


FIG.24A

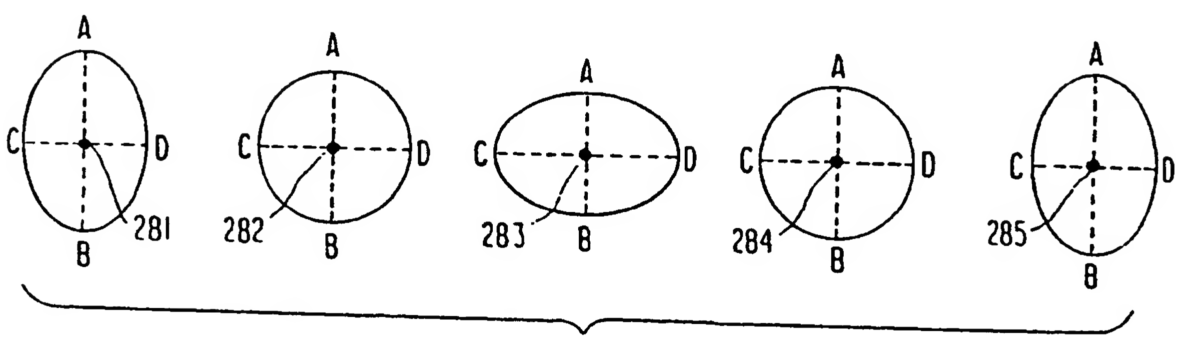


FIG.24B

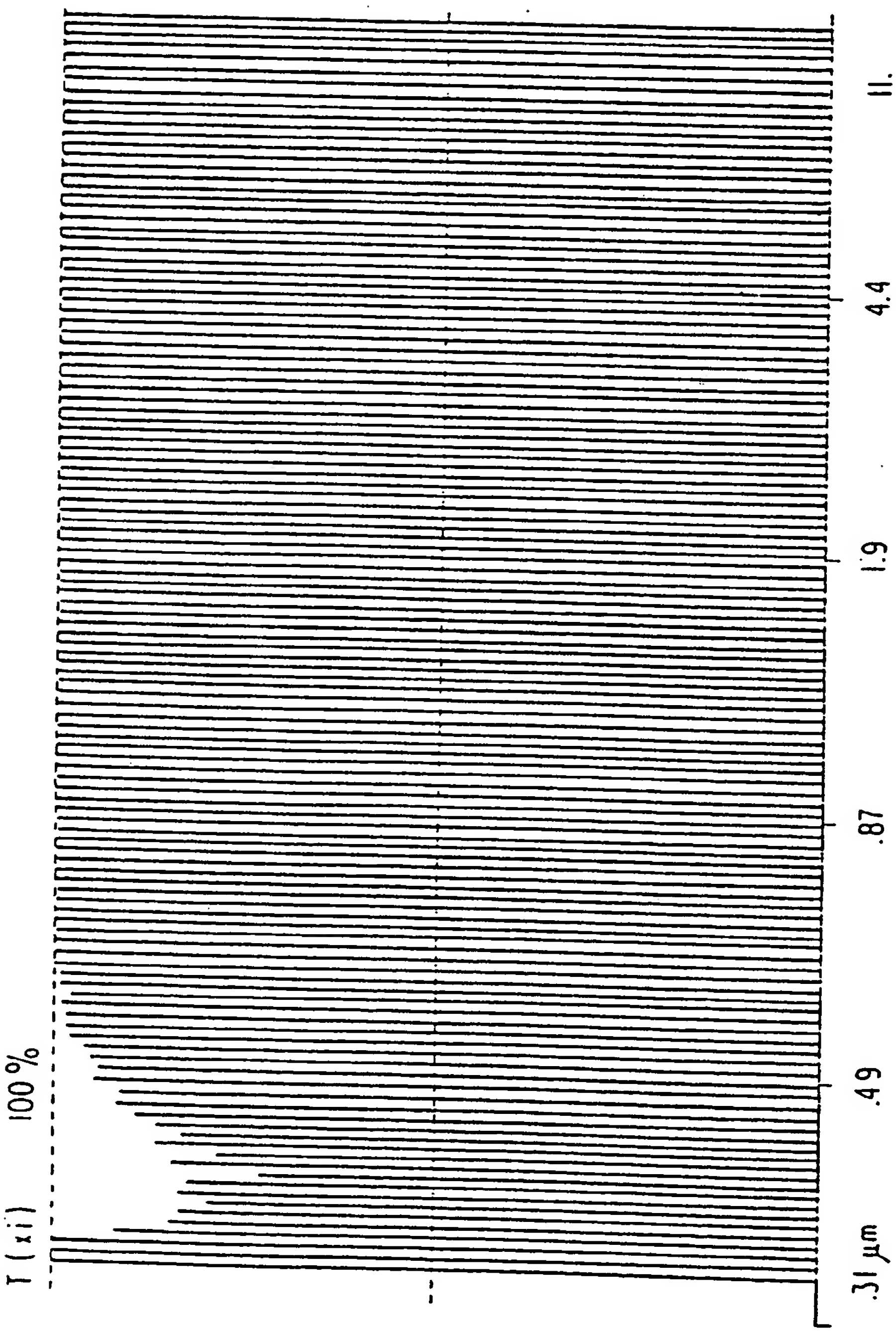


FIG. 25

INTERNATIONAL SEARCH REPORT

International Application No PCT/BE 90/00027

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC[5]: F 15 D 1/02, B 01 D 17/02, B 01 D 45/16

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC[5]	F 15 D 1/00, B 01 D 17/00, B 01 D 45/00, F 16 L 55/00

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	US, A, 3346117 (TEXACO INC.) 10 October 1967 see claim 1 --	1,3,4,5,13
X	DE, A, 1919503 (F.W. STROBEL) 29 October 1970 see claim --	1,3,4,5,31
A	DE, C, 843841 (GESELLSCHAFT FUR LINDE'S EISMASCHINEN A.-G.) 14 July 1952 see claims 1,2,3 --	1
A	FR, A, 730930 (IMPERIAL CHEMICAL INDUSTRIES) 26 August 1932 --	2

./.

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
12th October 1990	09. 11. 90
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	H. Ballesteros

Form PCT/ISA/210 (second sheet) (January 1985)

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	GB, A, 124130 (W.R. AUSTIN) 10 April 1919	
	--	
A	US, A, 4221671 (C.L. MEURER) 9 September 1980	
	--	
A	GB, A, 499024 (J. LOUMIET ET LAVIGNE) 16 February 1939	
	--	
A	US, A, 2351053 (F.F. KLETT) 13 June 1944	
	--	
A	FR, A, 2395061 (SOCIETE HAMON) 19 January 1979	
	--	
A	FR, A, 1095966 (P. CROSTI) 8 June 1955	

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. BE 9000027

SA 37452

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 29/10/90
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 3346117		None	
DE-A- 1919503	29-10-70	None	
DE-C- 843841		None	
FR-A- 730930		None	
GB-A- 124130		None	
US-A- 4221671	09-09-80	None	
GB-A- 499024		None	
US-A- 2351053		None	
FR-A- 2395061	19-01-79	BE-A- 867378 DE-A,B,C 2822376	23-11-78 11-01-79
FR-A- 1095966		None	

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82